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TETHERED BALLOON TRANSPORT SYSTEM: A PROPOSAL

William Frederick Graeter

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

TETHERED BALLOON TRANSPORT SYSTEM:
A PROPOSAL

by

William Frederick Graeter II

June 1978

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This report documents the impact of containerization on amphibious warfare, reviews the state of current lighter-than-air technology, traces the development of the commercial Balloon Transport System, summarizes the military development efforts at discharging containers using a balloon transport system, and makes specific recommendations for the implementation and further

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Tethered Balloon Transport System: A Proposal

by

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June 1978

ABSTRACT

This report documents the impact of containerization on amphibious warfare, reviews the state of current lighter-than-air technology, traces the development of the commercial Balloon Transport System, summarizes the military development efforts at discharging containers using a balloon transport system, and makes specific recommendations for the implementation and further development of a Navy Balloon Transport Facility (NBTF) which is designed to remove containers from non-self-sustaining containerships, transport them to the shore and deposit them in staging/handling areas inside the amphibious area of operations.

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I. INTRODUCTION

Past experience has repeatedly demonstrated that adequate sealift capacity is one of the determining factors in the support of military expeditionary forces on foreign shores. In future contingency situations, the Military Air Command's logistic aircraft, augmented by the commercial air fleet, will undoubtedly provide an important cargo-carrying capability. It is doubtful, however, if this capability will ever exceed 10% of the total dry cargo resupply requirement. The exact extent of the availability of future airlift is not known, but studies such as "The Port Capacity Estimator (PORTCAP)", developed in 1975 at the U.S. Army Command and Staff College, use the planning assumption that "five per cent of all cargo demands on the logistic system will be moved to the theater by airlift" (1). The remaining 95% will necessarily require transportation by sealift assets, but the availability and ability of the United States vessels to meet such sealift requirements also remains uncertain (2).

The Department of Defense has two basic sources from which to draw sealift capability: government-owned vessels and the U.S. Merchant Marine fleet. In peacetime, the military makes extensive use of the U.S. Merchant Marine in an attempt to ensure its availability in time of national emergency. This effort is reflected in legislation dating back to the Cargo Preference Act of 1904 which required all mil-

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itary cargo to be transported in U.S. flag vessels (2). In situations short of national emergency, the priorities for the augmentation of military shipping capability have been established by the 1954 "Wilson-Weeks" agreement between the Department of Defense and the Department of Commerce. This agreement is still in effect and establishes the following priorities for the ocean shipment of military cargo under conditions short of full mobilization (3):

1. U.S. privately-owned ships on their normal trade routes.

2. The charter of U.S. flag vessels.

3. Shipping provided by the National Shipping Authority or general agency agreement.

4. Foreign carriers in cases where cargo was shipped over routes not serviced by the nucleus fleet or U.S. flag vessels.

In the event of a declared national emergency, the President may invoke the emergency power contained in 46 USC 1242. This declaration automatically makes all the resources of the nation including the U.S. Merchant Marine fleet available to the government for the duration of the emergency.

To provide for contingency response, the Sealift Readiness Program was developed during the 1970's to meet shipping needs during less-than-full mobilization situations. The Sealift Readiness Program is effected through the Military Sealift Command's annual procurement of ocean transportation for the supply of U.S. peacetime military forces over-

seas. In order to bid on a Military Sealift Command Request for Proposal (RFP) for rates covering ocean transportation services, a carrier must commit 50% of his U.S. flag fleet to the program. The commitment of ships is considered a pre-condition to bidding, and any carrier committing ships must agree to make one-half of its commitment available within 30 days of notice and the remainder available within 60 days.

In addition to commissioned ships of the U.S. Navy and U.S. Merchant Marine, the Department of Defense has two other sources of government-owned or -controlled shipping assets: Military Sealift Command (MSC) and the National Defense Reserve Fleet (NDRF). The NDRF is administered by Maritime Administration (MarAd) and is primarily composed of ships originally built during World War II. These ships have been placed in the reserve fleet for emergency use. The size of the NDRF has declined from 2277 ships in 1954 (1) to 130 ships in 1975 (4). All ships remaining in the NDRF are over 30 years of age, and their material condition may require considerable time to activate.(5).

To further enhance the responsivemess of the NDRF and to ensure an emergency sealift augmentation capability, a Ready Reserve Force (RRF) composed of approximately 30 ships is being established inside the NDRF (6). These ships, capable of full operational status within 7-10 days following notification, are intended to provide a small number of ships with characteristics particularly desireable for military use (6).

The U.S. Navy does not possess an internal military logistics resupply sealift capability necessary for the support of sustained amphibious warfare operations. The MSC relying on the NDRF and/or commercial shipping fleets is expected to:

1. Augment the U.S. Navy ships in carrying out amphibious operations.

2. Provide for the resupply necessary to sustain the logistic needs of expeditionary forces.

The MSC's controlled fleet is deliberately kept small so that government resources will not be in competition with private shipping. It is used to meet the need for special shipping capabilities not normally available from civilian sources during peacetime. In 1977 there were 27 dry cargo ships in the controlled fleet, six government-owned (nucleus) ships, and 21 privately-owned (chartered) ships (6).

In addition to the 27 MSC-controlled ships, the approximately 8-10 ships presently in the RRF (6), and the questionable remaining NDRF assets, the Department of Defense has access to no other ships other than those found in the U.S. flag commercial fleets. Clearly, any contingency situation involving the Department of Defense requires a heavy reliance on the U.S. merchant fleet to provide the needed shipping capacity, and examples of past dependence can be cited. Chartering of U.S. commercial ships was a primary means of obtaining sealift capacity during the Lebanon crisis of 1958, the Berlin crisis in 1961, and the Cuban crisis in 1962 (4).

The nation's shipping resources were fully tested during the eight-year Vietnam War from 1965 through 1974. During this period, in addition to the 91 dry cargo ships owned and operated by MSC (7), private commercial sources, both tramp and berthline operators, contributed 172 chartered vessels at the peak of the Vietnam conflict in 1967 (8). The accelerating obsolescence of the NDRF and the declining number of MSC cargo ships implies even greater reliance on the commercial vessels of the U.S. Merchant Marine for support of future contingencies.

Despite all attempts by the government to stimulate the U.S. shipping industry with direct and indirect subsidies, the size of the U.S. merchant fleet has progressively declined. This decline and its impact on the available numbers of general dry cargo carriers between 1965 and 1973 is graphically displayed in Figure 1 with projections through 1980 (9). This data indicates an overwhelming shift from break-bulk-type dry cargo ships to containerships. It should also be observed that although the number of ships decreases by more than one-half, the total capacity of the fleet remains approximately stable at five million dead-weight tons. This can be explained by the fact that the modern containership's capacity is approximately four to five times greater, and it is twice as fast as the older Liberty and Victory-type freighters which have been displaced. The trend toward containerization is absolute and is being increasingly recognized by all military planners.

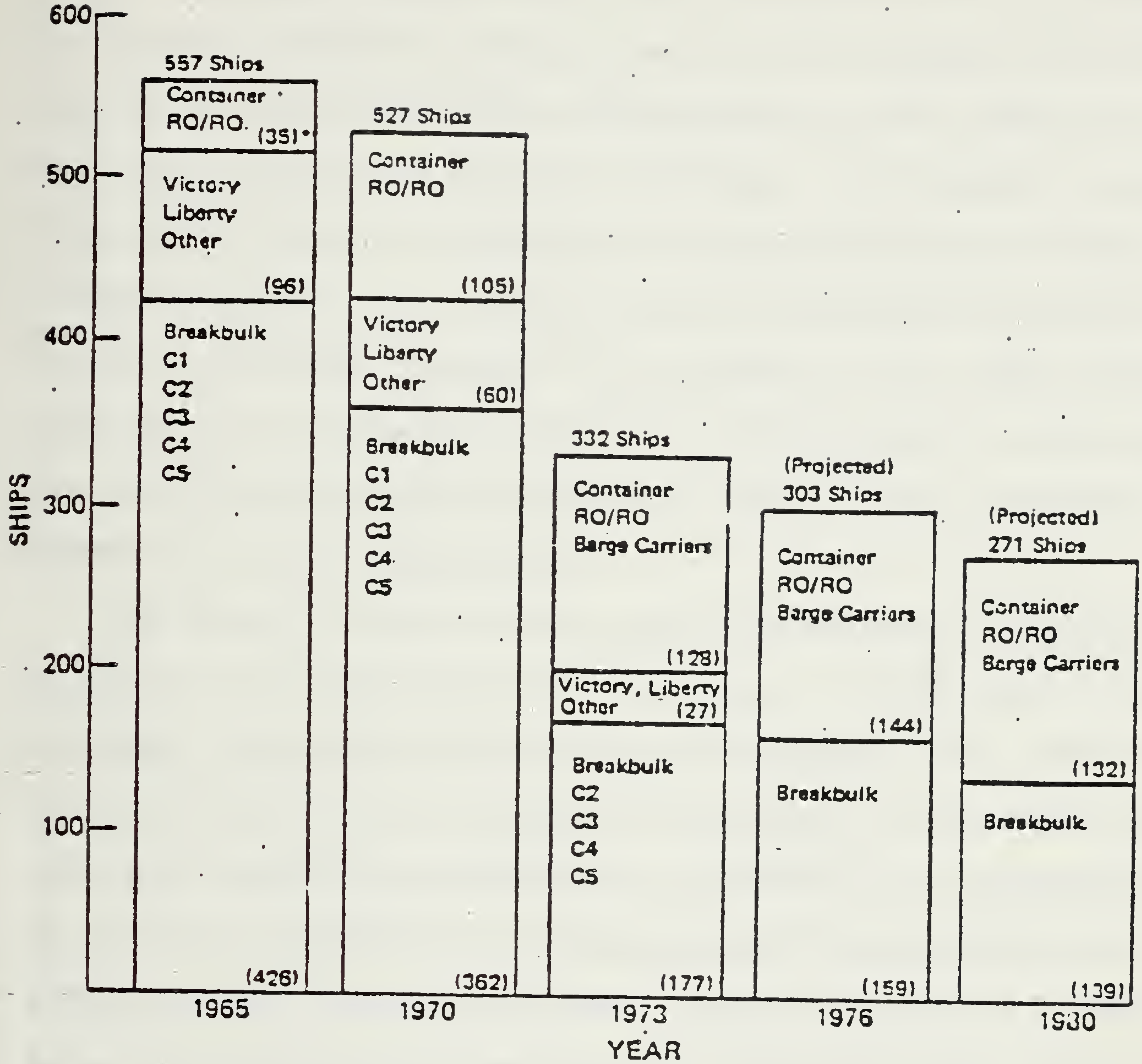

Figure 1. The Trend in Composition of U.S. Privately-Owned General Cargo Fleet.

Source: Walker, Application of Container Technology to United States Marine Corps Tactical Electric Generator Systems.

Economic forces in the commercial world precipitated this increasing trend toward the containerization of cargo, and recent estimates project that the U.S. commercial fleet will be approximately 90% containerized by the 1980's (9). The containerization concept involves: (a) loading a standard-sized box or container at an inland factory or transshipment point; (b) transporting this container by train or truck to an ocean terminal; (c) loading it on a ship which carries it to a distant point; (d) off-loading it; and (e) transporting it again by means of truck, train, or other means to a final destination.

The Navy, as well as the entire Department of Defense, supports the containerization concept. In 1977 55% of all military cargo was shipped via containership (6). DOD has adapted itself to this system by adopting the standard military van (MILVAN, an 8x8x20-foot container) as recommended by both the International Organization for Standardization (IOS) and the American National Standard Institute (ANSI). General transportation regulations throughout the services specify that the total weight of a loaded, 20-foot MILVAN shall not exceed 22.5 tons. The center of gravity of the loaded container is also specified and should not be further from the geometric center of the base than 10% of the distance to either side. The MILVAN is exactly the same size as the standard commercial 20-foot shipping van, and, for practical purposes, the two are interchangeable.

Commercial ships which regularly transport containers are special-purpose vessels with large holds designed for

this function. While the sizes of containerships may vary considerably, the trend is toward ever larger vessels. The majority of containerships in service today have widths of 78-92 feet, with some of the larger vessels reaching widths of 100 feet. Inside the holds of these special-purpose ships, there is a cellular framework constructed to hold the container and to prevent its lateral movement. This framework divides the cargo space into a series of vertical cells designed to carry self-supporting stacks of containers. The container cells are typically arranged with the long end of the container parallel to the ship's axis. A lateral clearance (rattle space) of 1.5 inches is provided between the container cell and the sides and ends of the container; therefore, once inside the cell, a container cannot be opened. During loading, as many as six containers are stacked in a single cell, and a hatch cover, some of which measure 32 x 40 feet and weigh 35 tons, is placed over a set of cells. Additional containers (two to four) are stacked on top of these hatch covers.

The older, conventional break-bulk ships, typical of the precontainer era, had their own winches and boom assemblies, making it possible for each ship to remove cargo from its hold and swing it over the side for further handling on the wharf. With the advent of the containership, however, both the ships and the wharves began changing. Precontainerization wharves were characterized by large warehouses and small outside staging areas. As the containerships evolved from self-sustaining to non-self-sustaining

designs, the cranes were removed from the containership. Their removal increased the containership's payload and decreased expenses by eliminating the continuous exposure of the shipboard crane to the ravages of the sea causing extensive maintenance problems. The cranes were located on the piers of specially-prepared container discharge berths which required large staging and handling areas for the containers. The ports then evolved into wide open areas with small warehouse facilities and large container staging areas. The modern containership berth, then, is characterized by wide piers equipped with large gantry cranes, and it is accompanied by 10-12 acres of hard-surface staging area behind the pier area to handle the container flows created during loading and discharge operations.

The non-self-sustaining containership cannot handle its own cargo, and supplemental lifting capabilities must be provided from external sources. As a result, these ships normally operate from one equipment-intensive port facility to another.

The initial step in offloading a containership alongside a wharf equipped with a huge gantry crane is to offload the deck-loaded containers and move them off the ship to the pier -- a distance which can exceed 100 feet. After the containers on deck are discharged, the large hatch cover and the below-deck containers are lifted out of the cells and discharged to the pier.

If containerships with a draft of 32-40 feet are to be used to support an amphibious landing at an unimproved site,

the resulting logistics over-the-shore operation will require that containers be offloaded from the non-self-sustaining containership and be transported to the beach by some means. The distance of this movement, the distance that the containership would anchor offshore plus the distance over which lighterage must operate, will vary from operation to operation. Offshore distance depends mainly on the slope of the sea floor: the distance must be sufficient to place the ship in deep enough water to prevent it from running aground. Although most Marine Corps studies specify a distance not to exceed one mile, there are places where sea-floor slope and the resulting water depth might place this distance in excess of one mile.

Since the number of ships has been reduced while speed and capacity per ship has increased, it follows that ship unloading and turn-around time becomes critical and must be kept to a minimum. To accomplish this, most commercial container ports have container discharge rates that average about 20 containers per hour. It then appears that a rate of 12 containers per hour or one container per five minutes could be established as a performance objective to guide Navy RPT&E and would be realistic.

Costs as well as operational problems would be reduced if the lifting mechanism used on the ship's deck also carried the container to and/or beyond the shoreline, easing the requirement for lighterage and double handling of cargo. One alternative for providing this capability exists with the use of a tethered balloon transport system similar to

that presently found in the logging industry.

It is the objective of this paper to document the impact of containerization on amphibious warfare, review the state of current lighter-than-air technology, trace the development of the commercial Balloon Transport System, summarize the military development effort at discharging containers using a balloon transport system, and to make specific recommendations for the implementation and further development of a Navy Balloon Transport Facility.(NBTF).

II. THE IMPACT OF CONTAINERIZATION ON AMPHIBIOUS WARFARE

A. CONTAINER CONSTRUCTION

A container can be defined as:

> ...an article of transportation equipment: (a) of a permanent character and accordingly strong enough to be suitable for repeated use; (b) especially designed to facilitate the carriage of goods by one or more modes of transportation without intermediate reloading; (c) fitted with devices permitting its ready handling, particularly its transfer from one mode of transport to another; (d) so designed to be easy to fill and empty; (e) having an internal volume of 1 m^3 (35.5 $ft.^3$) or more (10).

Containers are constructed so that they have rigid steel frames as a primary structure covered by thin light skins of steel, aluminum, fiberglass, or, in special cases, cardboard. Specially constructed corner posts with interlocking devices allow stacking in a variety of ways. Flooring materials are typically wood or metal; dunnage is inexpensive and is usually always recoverable and reuseable.

Since the initial introduction of containers in the mid-1950's, a number of special purpose containers have become common and are called by such names as "gondolas", "flat racks", "tandems", "rollers", "stackers", or "frames". Figure 2 (9) illustrates some of the more common types of containers now found in general use.

B. THE TRANSITION TO CONTAINERS

The container with its door-to-door convenience and efficiency brought revolutionary changes to the shipping industry. The old break-bulk fleet had flexibility in

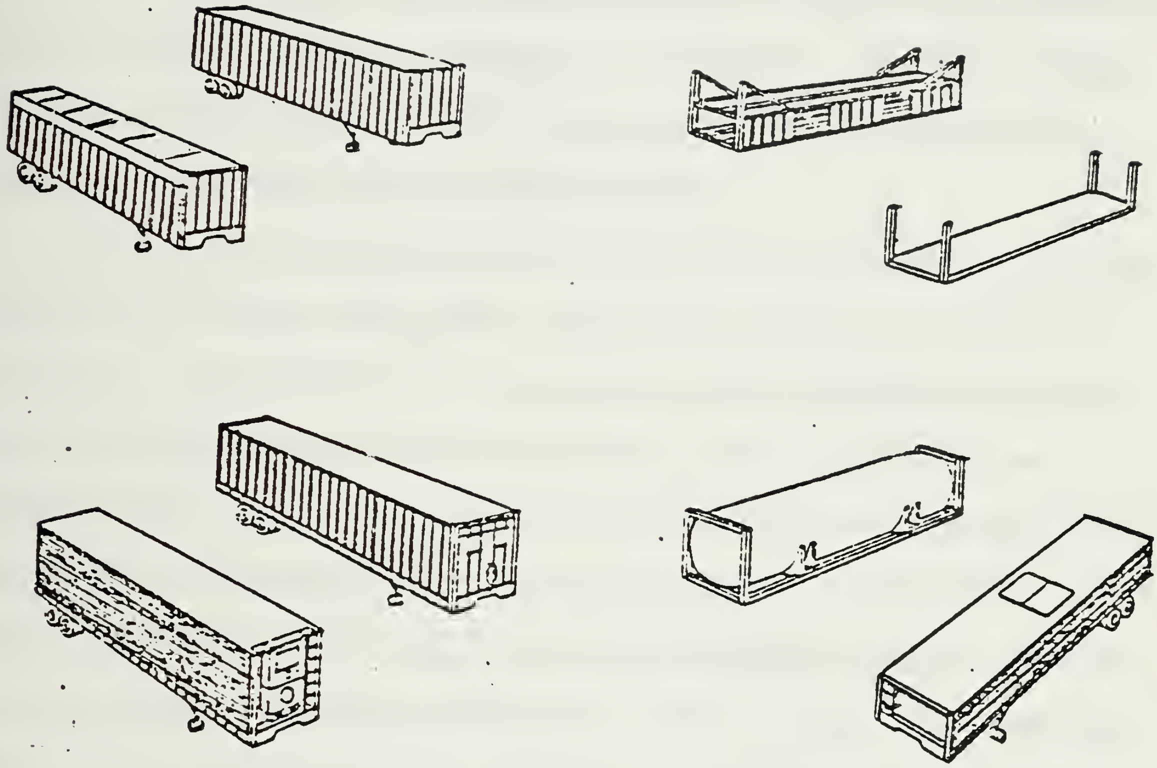

Figure 2. Types of Containers.
Source: Walker, Application of Container Technology to United States Marine Corps Tactical Electric Generator Systems.

terms of both numbers of ships and types of cargo that could be carried. Basically, however, they were designed to carry a large number of small unit (palletized) loads, and they were characterized by labor-intensive loading and unloading methods. The containership is just the opposite: it is larger, faster, designed to handle a smaller number of large (container-sized) loads, and it operates in an equipment-intensive port environment.

Ten years ago commercial fleets were composed of large numbers of highly flexible break-bulk ships, as shown in Figure 1. Investments in each ship were limited to 8-10 million dollars and daily operating costs were low -- $2500-$3000 (4). The old break-bulk ships served multiple ports to accommodate small aggregations of cargo and spent most of their time loading and discharging cargo. While experiencing high ship-to-shore costs, break-bulk vessels were remarkably flexible, capable of diverting off-route, carrying any cargo, and serving any port or need without substantially impairing schedules, disrupting shore operations, or adding to costs. These vessels were self-sufficient, interchangeable units. They could readily replace one another on the trade routes or satisfy military requirements with equal facility. Overhead costs were low, so they could stand by offshore, be stockpiled in the reserve fleets, or laid up by private operators during periods of declining commerce without undue financial burden.

The new containerships, on the other hand, are much more expensive and accrue the substantially higher daily costs of

up to $10,000-$20,000 (4). They cannot be diverted from high density routes to search for small cargo allotments or stand by for long periods of time to await loading or discharge. Containerships are, however, several times as productive as the break-bulk ships they replaced. Containerships enable operators to multiply ship-to-shore productivity and substantially reduce vessel time in port. The new ships require enormous aggregations of cargo for optimum utilization, and this necessitated major alterations in modes of operation.

The number of ports directly served by the cargo-carrying line-haul ships has been severely reduced. For example, in the Pacific Basin, five to nine ports were served at each end of the route in 1963; this number has now been reduced to one or two (4). Productivity gains achieved by containerships have necessitated handling single, large, heavy loads and have created a loss of service flexibility. The new containerships are fast, intermodal vessels accounting for an everincreasing percentage of U.S. merchant ship ton-mile capacity. Therefore, it is important to insure that high speed and fast turnaround capabilities are achieved. Future logistics planning must include a provision for rapid off-loading and fast turnaround to realize the full potential of high productivity ships. Holding vessels for long periods of time in an objective area may not be an option in future contingencies.

This change has not been without its evolutionary aspects. Within two decades ships representing various as-

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pects of containerization were placed in service, then rendered obsolete as the economics of the trade routes changed. As old break-bulk freighters were transformed into the modern non-self-sustaining containerships, the order of progression was: break-bulk cargo carriers, converted break-bulk carriers, hybrids (half break-bulk, half containership), self-sustaining containerships, and, finally, non-self-sustaining containerships. The new containerships were designed to be faster in transit, and, as the ports became more equipment-intensive, the containerships became increasingly streamlined.

Although almost any of the various types of containerships built since the early 1950's can be found in service on one or another of the various trade routes, containerships are classified in two general categories: self-sustaining and non-self-sustaining. The self-sustaining containership has the ability to load and discharge its cargo of containers by means of integral, onboard cranes, and, therefore, minimal assistance from ports (i.e., deep draft berths with shore-based gantry cranes and large staging areas) is necessary. The non-self-sustaining containership, however, has no onboard crane and is completely dependent on external dockside gantry cranes for loading and discharge. The importance of these characteristics of the containership to the military planner cannot be overemphasized. If the non-self-sustaining containership is to be used in support of an expeditionary force on a foreign shore, that expeditionary force must either control a fixed port with high-

ly developed lift facilities or be outfitted with equipment capable of discharging these ships across undeveloped beaches. Unfortunately, all too many military officers fail to grasp the full impact of this fact.

In the early stages of containership construction, the self-sustaining design was predominant. However, as trade routes were developed and the impact of containerization economics began to be felt, principal ports and major containership operators built elaborate port facilities with pierside cranes. Thus, the need for the additional expense of constructing containerships with integral cranes no longer existed. This trend has progressed to the point where all containerships delivered or under construction in the United States since 1975 were of the non-self-sustaining design (11). It is, of course, impossible to know how far the trend will go, but in 1975 it was estimated that more than 50% of the available U.S. flag merchant sealift capability would be in non-self-sustaining containerships by 1976. In the period 1975 to 1985 the U.S. commercial fleet is expected to double its percentage of containerships while the number of break-bulk ships will continue to decrease, and by the year 2005 it is anticipated that almost all commercial shipping will be unitized (12).

C. CONTAINER SIZES

Simultaneous with the containerization evolution there occurred a proliferation of container sizes as each individual company produced its own unique size and shape based on

its own unique requirements. The American National Standards Institute (ANSI) and the International Organization for Standardization (IOS) have attempted to achieve standardization of containers in order to promote commonality between shipping modes. Although standardization has not as yet been effectively achieved, the most predominant sizes are grouped into 8x8x20-foot and 8x8x40-foot sizes, and in most cases container capacities are commonly expressed in twenty-foot equivalents.

There are, however, exceptions to those standardization efforts. In the United States the most notable of these are the Matson 8x8x24-foot and the SeaLand 8x8x35-foot containers. The Matson and SeaLand companies were building containers and containerships before IOS was established, and their container sizes were dictated by west and east coast highway regulations. Today these companies' investments are so substantial that their sizes are accepted.

There appears to be a move in the shipping industry toward the larger 8x8x40-foot containers (9), and it is this container that the military must ultimately learn to efficiently handle in all environmental conditions as well as under stress. The military must be able to use whatever containership is made available for DOD cargo. In a non-declared war DOD must "make do" with whatever shipping is allocated to it by industry, and in a declared war the demands on the limited merchant fleet will be so great that any and all ships are potential candidates. Therefore, achieving the ability to efficiently handle the 40-foot container any-

where and at at any time is a realistic DOD goal.

D. PAST EXPERIENCE WITH CONTAINERIZATION

Department of Defense experience with containerization in peacetime has been very successful, and the concept has increased in importance for many of the same reasons that have enhanced its value in commercial industry. In 1977, for example, approximately 55% of all military cargo was transported by container (6), and it is anticipated that this trend will continue. The only experience the military has had with containerization in support of an expeditionary force, however, occurred during the Vietnam conflict.

In 1967 the use of large intermodal containers and containerships for cargo movement to Vietman was initiated through a contract with SeaLand Service, Inc. (13) with container shipments consigned to Da Nang using self-sustaining containerships (14). Later, after port facilities and gantry cranes were constructed, service was extended to Cam Ranh Bay using both self-sustaining and non-self-sustaining containerships. Eventually the container service was extended to Qui Nhon and Saigon using self-sustaining containerships (14). This container service successfully transported all classes of cargo including ammunition. In 1970 a most significant test of the intermodal container occurred when 226 containers of ammunition were shipped by containership from CONUS to Vietnam (13). This test was so successfull that military personnel in Vietnam recommended the permanent use of this method (13).

The shipment of cargo to Vietnam in containers resulted in a considerable cost saving realized through a reduction in transit loss, reduced damage, and less pilferage, in addition to savings resulting from reduced turnaround time (10). It has been estimated that over ¼ billion dollars in savings and cost avoidance could have been realized if maximum use of containerization had been possible in Vietnam (15).

E. PROBLEMS WITH CONTAINERIZATION

This use of intermodal containers, however, was not attempted until fixed port facilities were secured and outfitted (13). Self-sustaining containerships were primarily used. No attempts were made to discharge containers across undeveloped beaches. Subsequent efforts to adapt this shipping mode to the logistics of the over-the-shore operations have been increasingly successful, but the improvement of these adaptations is necessary in order to make use of the containership in an austere military environment.

Dependence on the U.S. merchant fleet to provide logistic support for future expeditionary forces will continue. One of the most serious problems facing military logisticians is that of using the non-self-sustaining containership in an operation where the containers must be discharged, transported to the shore, and handled acorss an undeveloped beach, or where the use of the port facilities has been rendered unavailable by military or political action.

F. SURFACE SOLUTION

The solution to the time and handling dilemmas presented

by containerization is being considered by a variety of agencies in the Department of Defense. This problem occurs in four stages:

1. Discharging the non-self-sustaining containership in the area of operations.

2. Transporting the container to the shore.

3. Handling the container across the beach.

4. Managing and handling the container ashore.

The following is a brief overview of surface component concepts relating to the above problem areas insofar as they are available in unclassified documents.

1. <u>Container Handling</u>

Handling containers across the beach is approached by the Navy using the elevated causeway concept illustrated in Figure 3 (12). The Army has approached this same problem with a large crane which can be broken down into small increments for shipment and reassembled at the waterline where it will be used to discharge containers from lighterage. Both these concepts have been tested within the last year by the Joint Logistics Over-the-Shore Tests. Initial results have been favorable.

2. <u>Container Transport</u>

Transporting containers to the beach is a solveable problem, and most studies consider various mixes of the types of self-propelled landing craft currently available: the LCM-6 (Figure 4), the LCM-8 (Figure 5), the LCU-1610 (Figure 6), the C-150 air cushion vehicles Jeff A and Jeff B (Figures 7 and 8), in addition to the causeway ferry (Figures 9 and

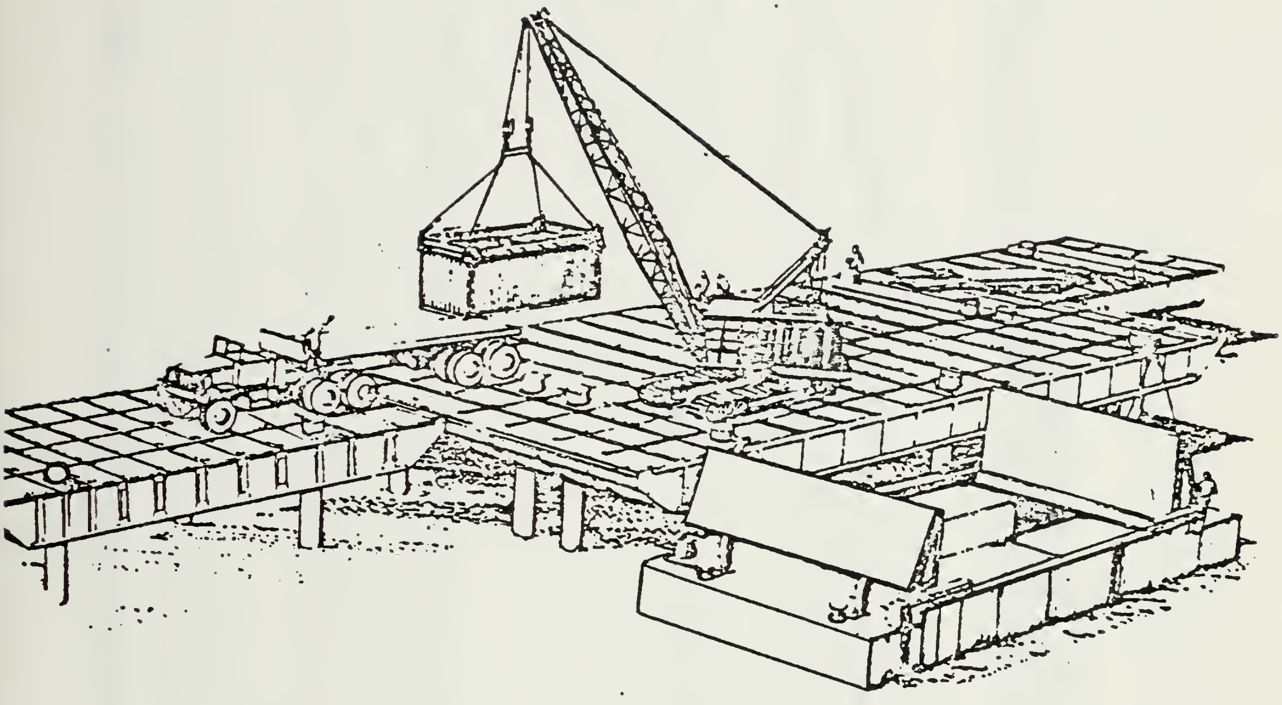

Figure 3. The Elevated Causeway.
Source: Naval Facilities Engineering Command, Naval Beach Group Capabilities in Support of SMLS or Barge/Container Missions.

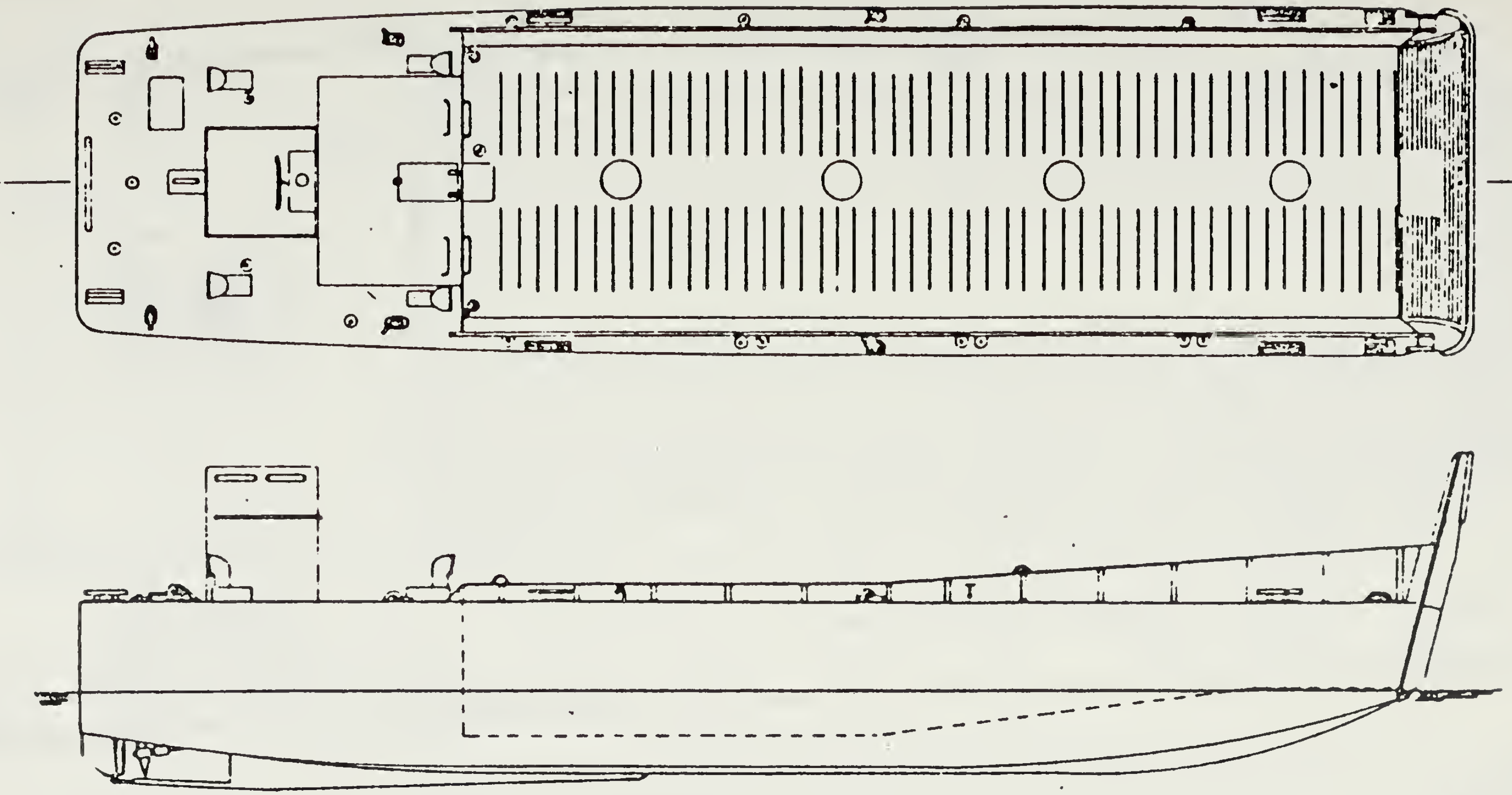

Figure 4. The LCM-6.
Source: David W. Taylor Naval Research and Development Center, <u>Follow-On and Resupply Shipping Assets for a Representative Marine Corps Situation</u>.

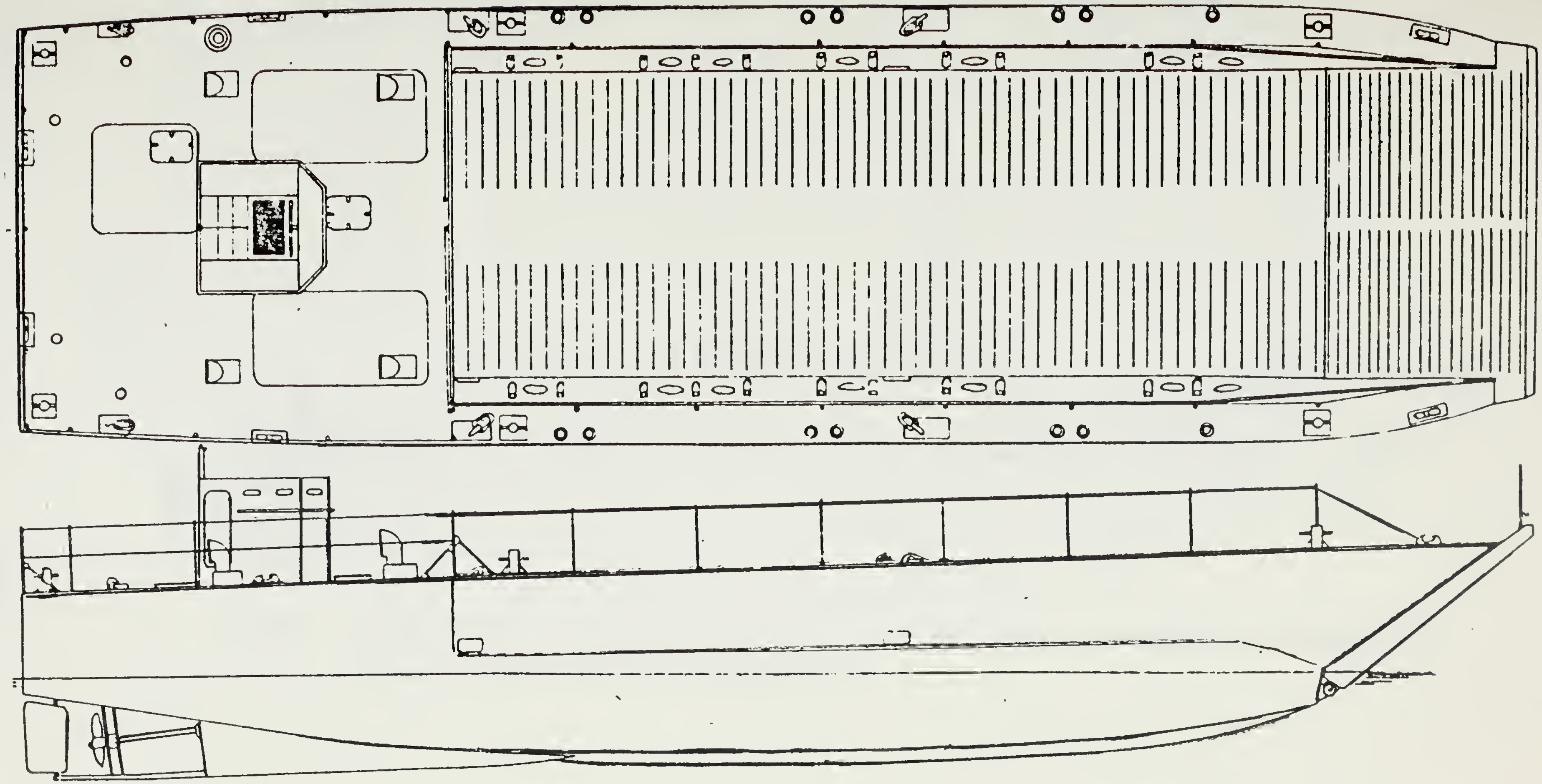

Figure 5. The LCM-8.
Source: David W. Taylor Naval Research and Development Center, <u>Follow-On and Resupply Shipping Assets for a Representative Marine Corps Situation</u>.

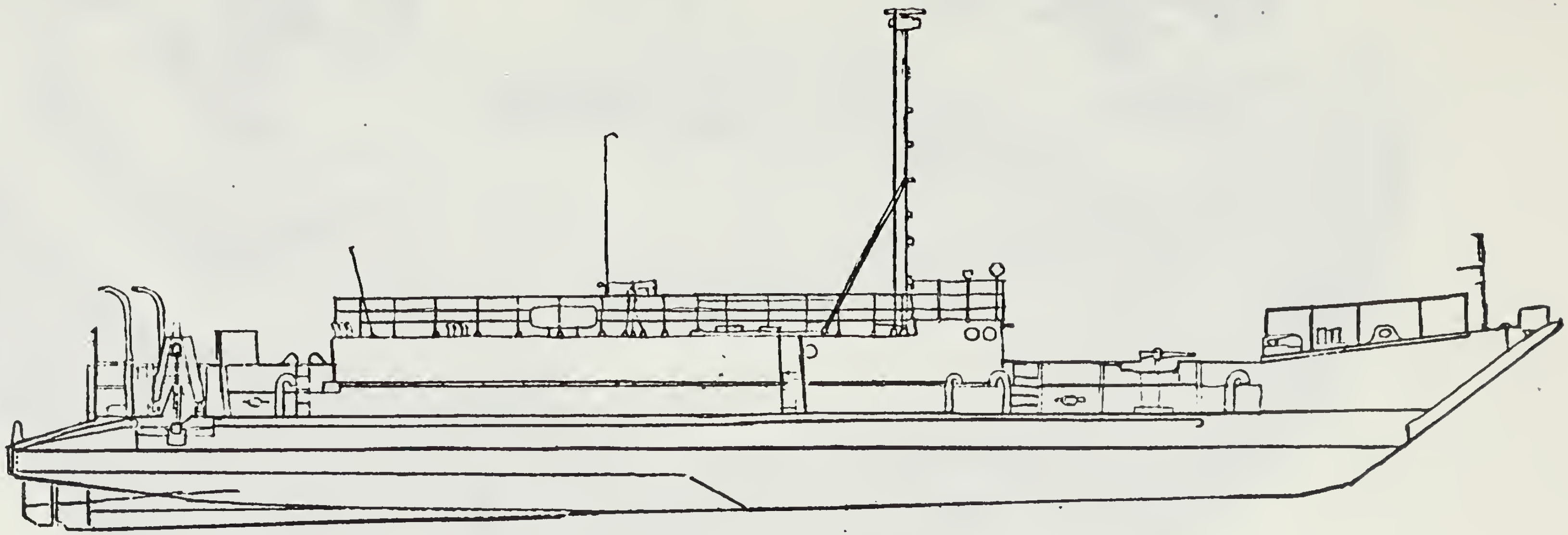

Figure 6. The LCU-1610.

Source: David W. Taylor Naval Research and Development Center, Follow-On and Resupply Shipping Assets for a Representative Marine Corps Situation.

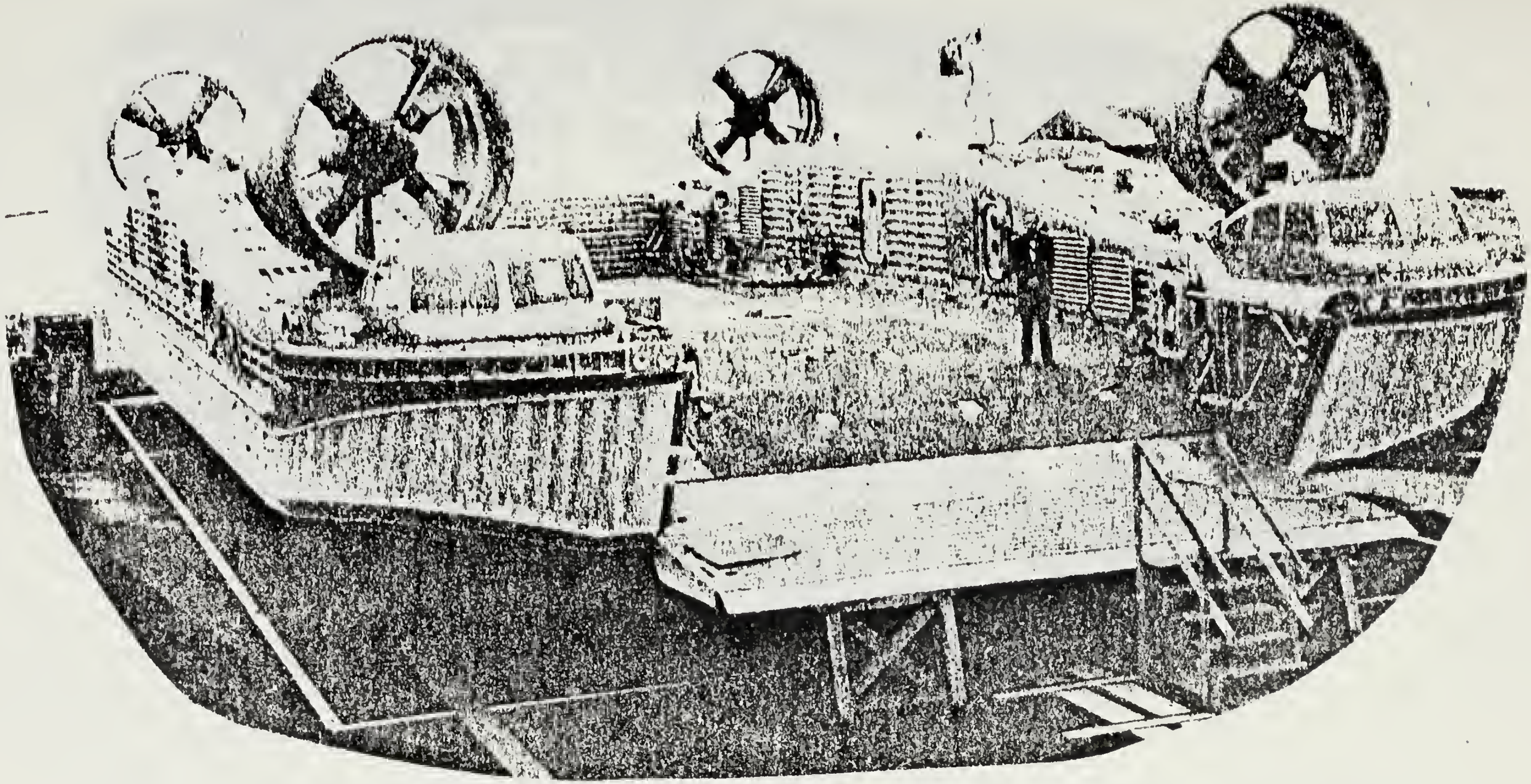

Figure 7. The C-150 Proposed Air Cushion Vehicle - Jeff A.
Source: Aviation Weekly (May 23, 1977), Air Cushion Vehicle Readied for Testing.

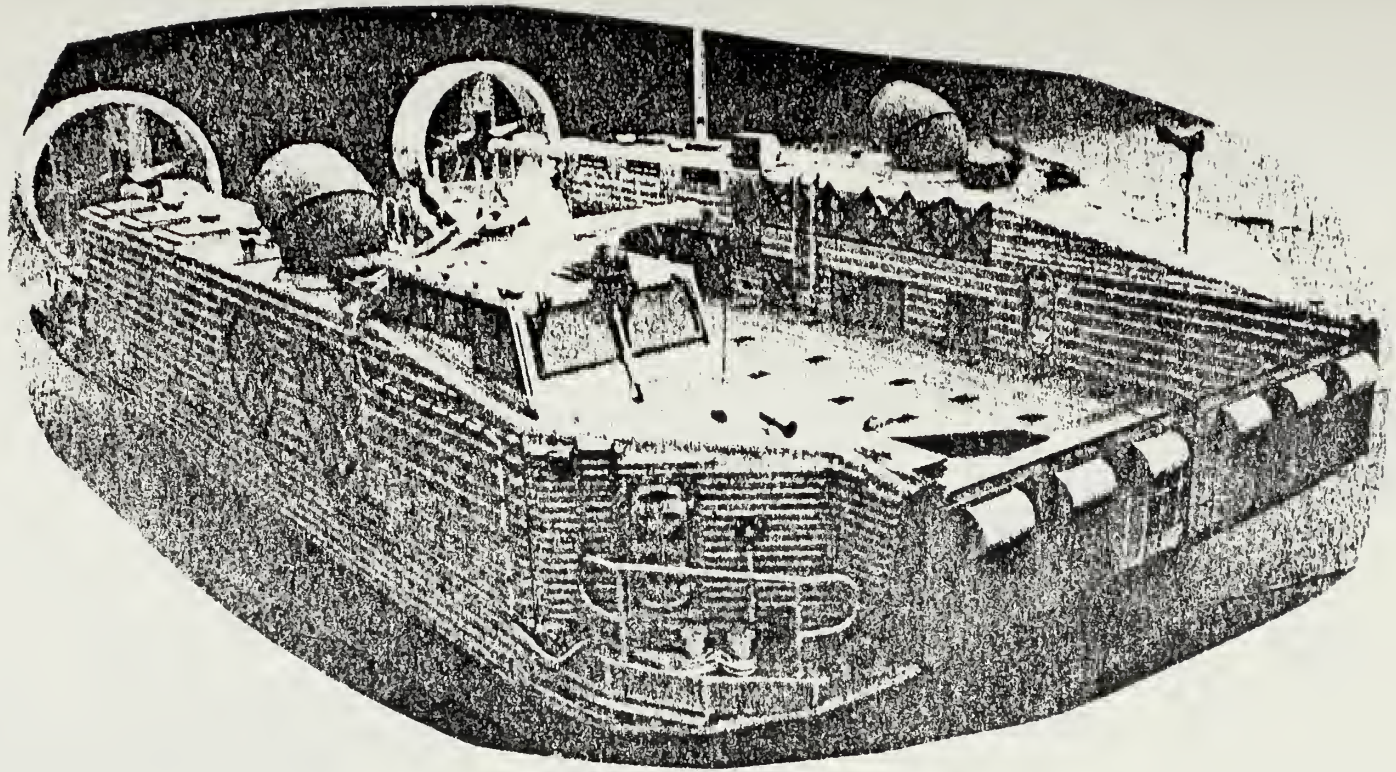

Figure 8. The C-150 Proposed Air Cushion Vehicle - Jeff B.
Source: Aviation Weekly (May 23, 1977), Air Cushion Vehicle Readied for Testing.

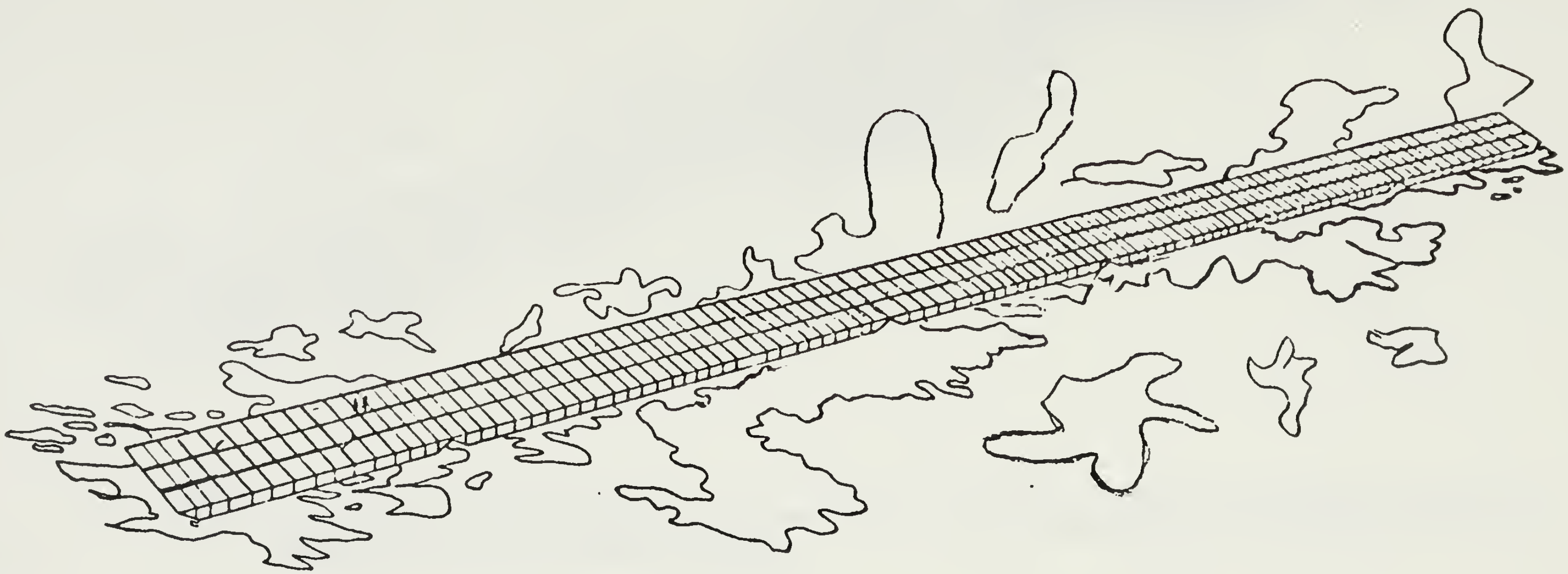

Figure 9. The Causeway Ferry (LORO).
Source: Author's Conception.

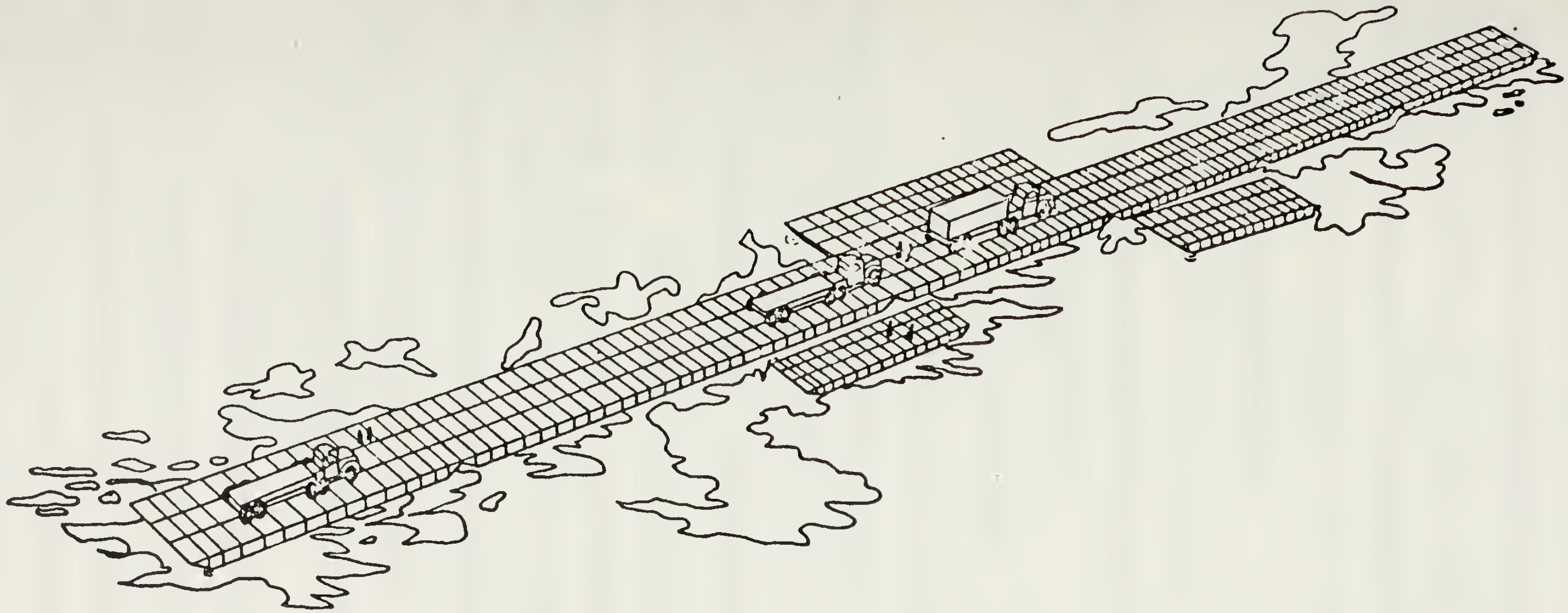

Figure 10. The Causeway Ferry (RORO).
Source: David W. Taylor Research and Development Center, Follow-On and Resupply Shipping Assets for a Representative Marine Corps Situation.

10). The characteristics of these craft are shown in Table I. The LCM-6, LCM-8, and LCU-1610 are demonstratably successful and are adequate if available in sufficient numbers. The causeway ferry is successful, adequate in sufficient numbers, and efficient. Air cushion vehicles have been demonstrated in support of container operations, and several logistics studies consider them a viable option (16).

3. Container Discharge

A solution to the problem of the discharge of the non-self-sustaining containership has been seriously attempted by the following approaches.

a. Crane on Deck (COD) -- Figure 11 (17)

Mobile cranes are placed on the deck of non-self-sustaining containerships in order to make the ship self-sustaining. This method was first attempted during OSDOC II (18) and again in the recent Joint LOTS exercises with success. The system is expensive in that two to three cranes, each of a nominal 150-200-ton capacity, must be placed on each deployed containership in the pipeline. This system provides the maximum level of system redundancy on a per ship and per operation basis.

b. Temporary Container Discharge Facility (TCDF) -- Figure 12 (17)

The TCDF method utilizes a ship/platform fitted with cranes to provide deployable container handling facilities for offloading non-self-sustaining containerships. The non-self-sustaining containership is placed alongside the TCDF (which serves as a floating pier), and the containers

Craft	Speed	Capacity
LCM-6	9 knots	34 short tons
LCM-8	9 knots	60 short tons
LCU-1610	11 knots	180 short tons
C-150 (Jeff B) Air Cushion Vehicle	50 knots	75 short tons
Causeway Ferry	4 knots	100 tons of cargo per causeway section with one foot freeboard. Other calculations are variable; e.g., 320 measurement tons for containerized cargo or 500 measurement tons for Ro/Ro applications.

Table 1. Characteristics of Transfer Craft.

Source: David W. Taylor Naval Research and Development Center, Follow-On and Resupply Shipping Assets for a Representative Marine Corps Situation.

are discharged onto lighterage. This system's productivity depends on the size of the platform from which the cranes operate (hence it is potentially insensitive to sea motions) (19). Productivity would be poor for small barges, but very good for a ballasted ship hull such as a tanker. This system has the advantage of arriving in the amphibious area of operations with the non-self-sustaining containership.

c. Temporary Container Discharge Facility/Crane Transfer (TCDF/CT)

The TCDF/CT concept involved a ship/platform fitted with very large cranes (about 600-800-ton capacity) to transfer smaller mobile (150-ton) cranes from empty to full non-self-sustaining containerships at the area of operations. These non-self-sustaining containerships are then made self-sustaining only in the amphibious area of operations. The size of the very large crane necessary to effect transfer of the smaller crane posed unique platform problems and associated limitations in ordinary 20-knot transportability. The container handling productivity for these ships is less than for COD ships due to the smaller mobile cranes, and additionally the transfer of the small cranes is so sensitive to sea conditions that a recommendation has been made to discontinue it as a practical solution (19).

d. Crane on Deck/Barge (COD/Barge)

The COD/Barge concept involves a very stable barge fitted with a large crane, or a floating crane, being towed (at five knots) to the amphibious area of operations

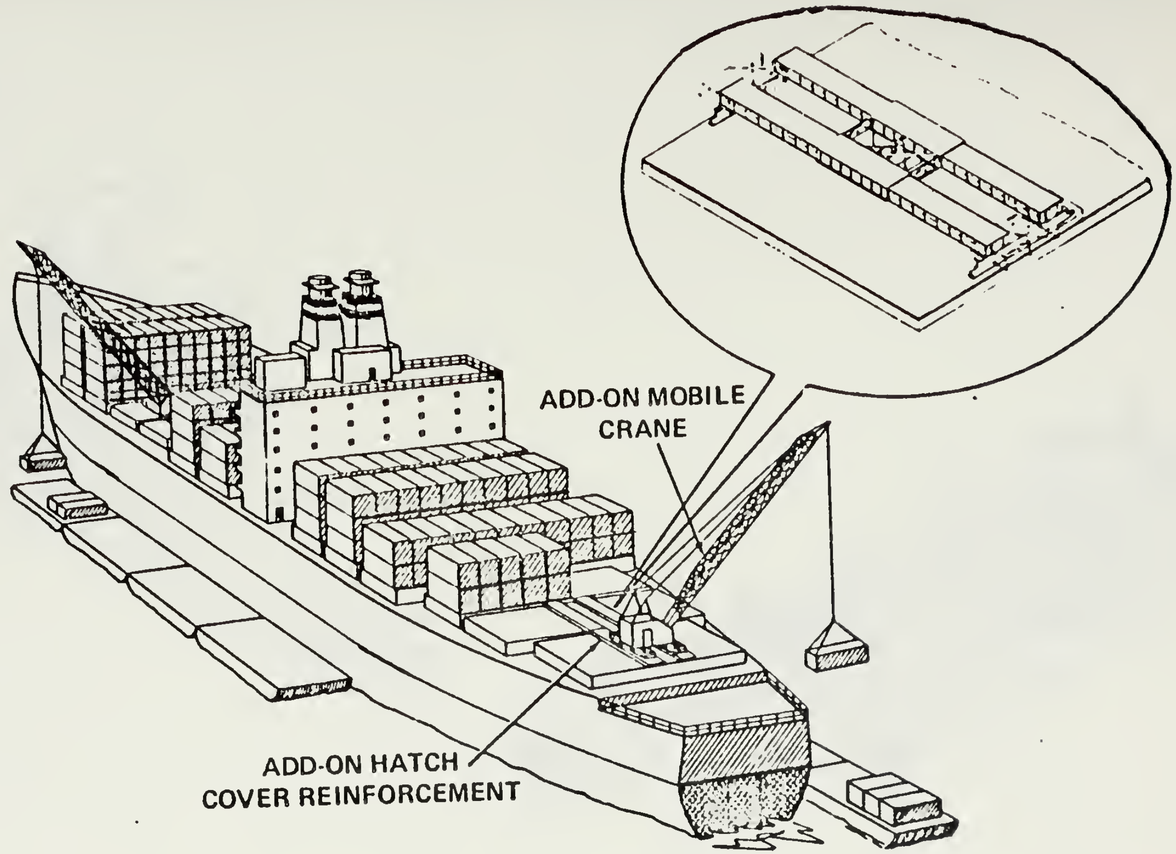

Figure 11. The Crane on Deck (COD).
Source: Naval Facilities Engineering Command, <u>Container Off-Loading and Transfer System (COTS)</u>.

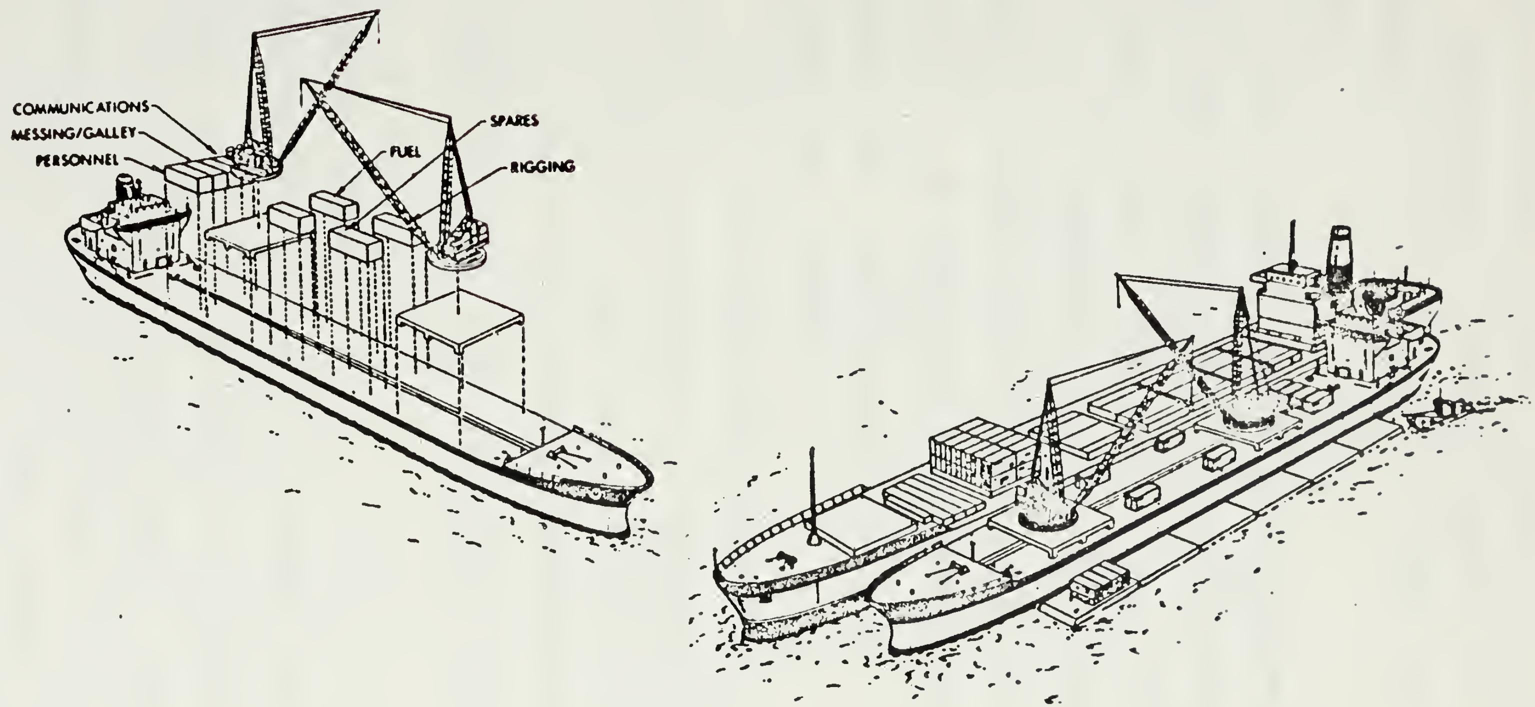

Figure 12. The Temporary Container Discharge Facility (TCDF).
Source: Naval Facilities Engineering Command, Container Off-Loading and Transfer System (COTS).

where it is to be used as the temporary container discharge facility. This method is very productive and cost effective. The COD/Barge concept attempts to combine the advantages of two systems:

(1) Initial deployment achieves speed and redundancy by using COD's on all non-self-sustaining containerships in the pipeline. This action buys time for --

(2) The arrival of the towed barge TCDF's.

In terms of total system capability from a conceptual point of view it is the preferred method because of its cost effectiveness (19). Practically, however, it has several disadvantages which defeat it:

(1) The barge/floating crane can only be towed at five knots and is therefore vulnerable in transit.

(2) The barge-crane combination is too sensitive to sea motion for sustained operations and available floating cranes are too slow to achieve high productivity rates.

4. Surface Summary

The "Service Solution" involves combining the surface components together to create a system capable of discharging containerships (or any ships). The mix of components depends on a variety of factors such as mission, component availability, type of cargo, ships to be worked, depth of water, sea conditions, etc. A typical operation (Figure 13) (17) might occur in the following sequence: (1) assault (D-Day), amphibious warfare troops arrive at

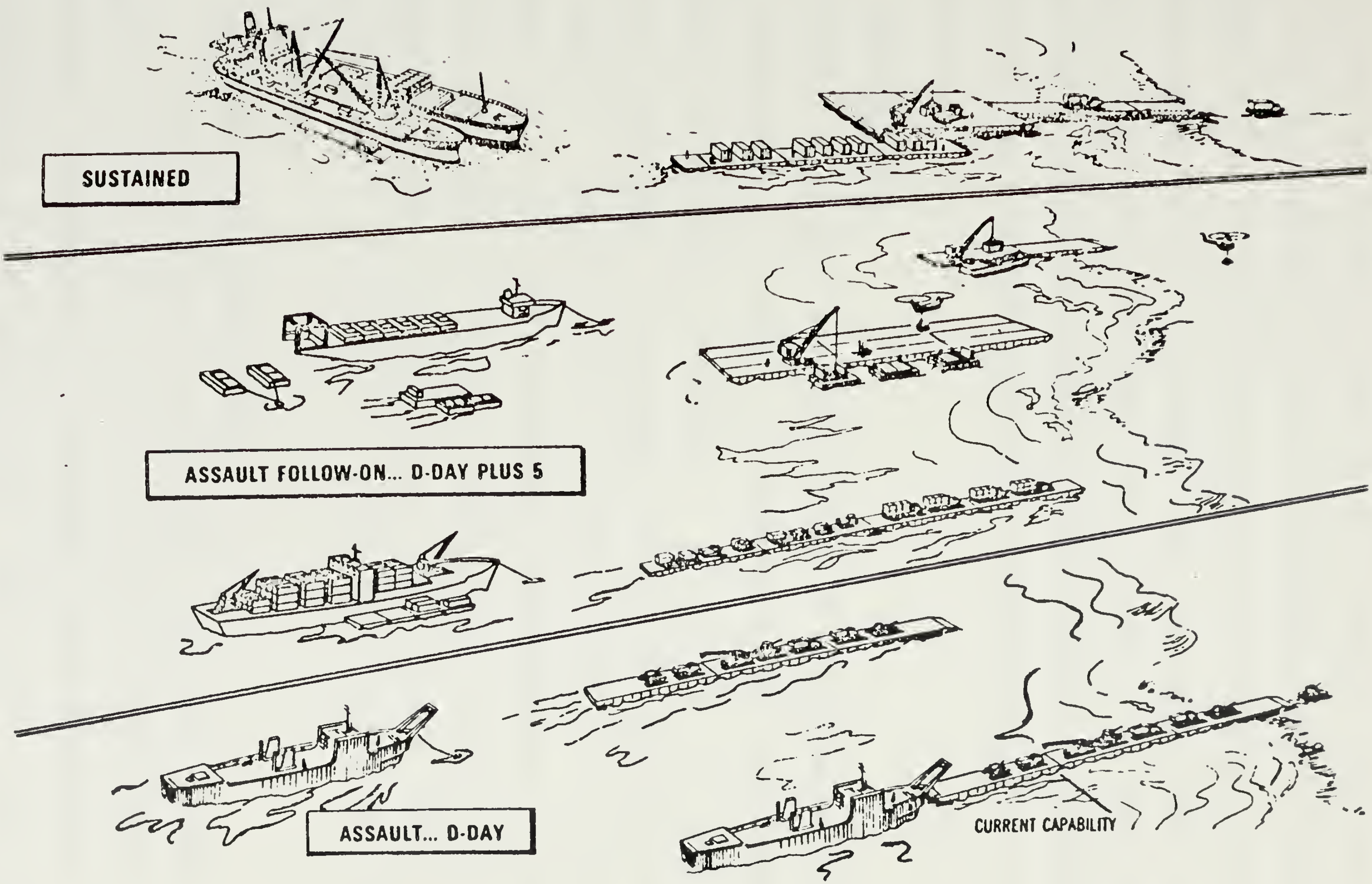

Figure 13. Sequences of Amphibious Off-Loading Operations.
Source: Naval Facilities Engineering Command, <u>Container Off-Loading and Transfer System (COTS)</u>.

the amphibious area of operations and land the assault echelon of the expeditionary force; (2) assault follow-on (D-Day + 5), the assault, follow-on echelons arrive in merchant shipping (such non-self-sustaining containerships as used in this phase would be equipped with cranes on their decks to make them self-sustaining; after a time, as the logistics effort becomes sustained, TCDF's arrive to discharge the remaining non-self-sustaining containerships in the pipeline).

G. AIR SOLUTION

Another approach to the dilemma of containerization, the air approach, attempts to develop an air frame that will deliver the container straight to the beach. If feasible, the "air solution" is extremely attractive because it reduces the number of modes, double handling, amount of support equipment, and associated interface coordination factors to the lowest feasible level. Ideally such a system would complement the surface system rather than compete with it. To date the search for an "air solution" has taken the following direction.

1. <u>Heavy Lift Helicopter</u>

The most obvious vehicle for this role is the helicopter, and the feasibility of utilizing a helicopter to discharge self-sustaining containers has been tested using the CH-54 and CH-47C helicopters. The cost of procuring sufficient helicopters and the problems of maintaining these aircraft in the area of operations are, however, important

points of criticism as to the logistic supportability of this approach. To date, the Navy has not been able to pursue the idea of discharging non-self-sustaining containerships with helicopters due to problems associated with the removal of hatch covers (25-35 tons) and the expense of procuring and maintaining the helicopters. The Navy, therefore, has not programmed the purchase of helicopters exclusively for this specific mission.

The Marine Corps, however, with its new CH-53E helicopter (equipped with a two-point lift system) will have the technical ability to offload weight-limited containers from above deck positions. This ability is limited to containers with a maximum weight of 32,000 pounds (20), and the use of special adaptive slings is required. Since the CH-53E cannot lift the containership hatch covers, below deck containers cannot be lifted unless the containership is self-sustaining or the hatch covers are lifted by an external source such as a COD.

The Army was developing a Heavy Lift Helicopter (HLH) that was to be used for the discharge of 20-foot containers from non-self-sustaining containerships; however, Congress has withdrawn program funding. This developmental effort was apparently stopped because of high RDT&E costs and high estimated unit costs for the 23.5-ton capable helicopter. It is, of course, speculation to project how mission-effective the HLH would have been in view of the non-self-sustaining containership hatch cover's weight, which can run as much as 25-30 tons.

The proponents of the helicopter discharge system argue in its favor due primarily to the system's speed, avoidance of double-handling of containers, and the elimination of sea-and surf-sensitive lighterage operations. The economic costs of the system do not place it in a favorable position, however.

2. Short Haul, Heavy Lift Vehicle

Realizing that there is a continuing shift toward the use of standardized containers for the movement of military supplies with weight handling requirements greatly in excess of existing and planned air systems, the Navy recently issued an Operational Requirement (OR) for a short haul, heavy lift air system. This requirement (OR-W1019-SL) conceptually describes an air system that would potentially have greater capabilities than planned air and surface off-load systems and would be able to lift and transport containers ship-to-shore, shore-to-ship, and ship-to-ship under all-weather, day-and-night conditions.

The Navy's short haul, heavy lift development has been funded by NAVAIR. To date two approaches to the short haul, heavy lift requirement have been identified. Studies (21, 22,23, 24) and limited model testing (25,26) have indicated that both vehicles show potential. While known by various names, these vehicles can best be described as "Roto Balloon" (Aerocrane) and "Quad Rotor" (Helistat). Both vehicles are hybrid buoyant air vehicles, and they differ from previous lighter-than-air devices in that they combine buoyant lift with dynamic lift provided by using rotary wing devices for

for propulsion, control, and lifting power.

a. Roto Balloon (Aerocrane)

The Roto Balloon (Aerocrane) concept involves a hybrid buoyant air vehicle which theoretically creates an ultra-heavy lift capability by combining the aerostatic lift force of the balloon with the aerodynamic lift force of the helicopter (see Figures 14, 15). The illustrations show a conceptual 50-ton aerocrane with four, 112-foot by 18-foot wings, each having a 200-HP turboprop engine mounted on a 150-foot sphere (23). The low pressure, helium-filled sphere, with an internal ballonet, provides an aerostatic lift equal to all the vehicle's structural weight, plus 50% of the sling load lifting weight. The four wings develop the remaining sling load lift and provide all force required for vehicle movement as they rotate at ten revolutions per minute (rpm) during flight. Therefore, in flight the balloon and wings rotate as the vehicle moves through the air to achieve its aerodynamic lift (23). The control cab, mounted on the bottom of the vehicle, would be powered and geared to rotate at the same speed and in the opposite rotation to the aircraft structure to maintain a still position relative to the buoyant air vehicle. The development of the aerocrane concept is independent of any specific size or weight-carrying capability. The one illustrated could easily be various sizes depending on the desired lift capacity.

b. Quad Rotor (Helistat)

The Quad Rotor (Helistat) concept is a hybrid

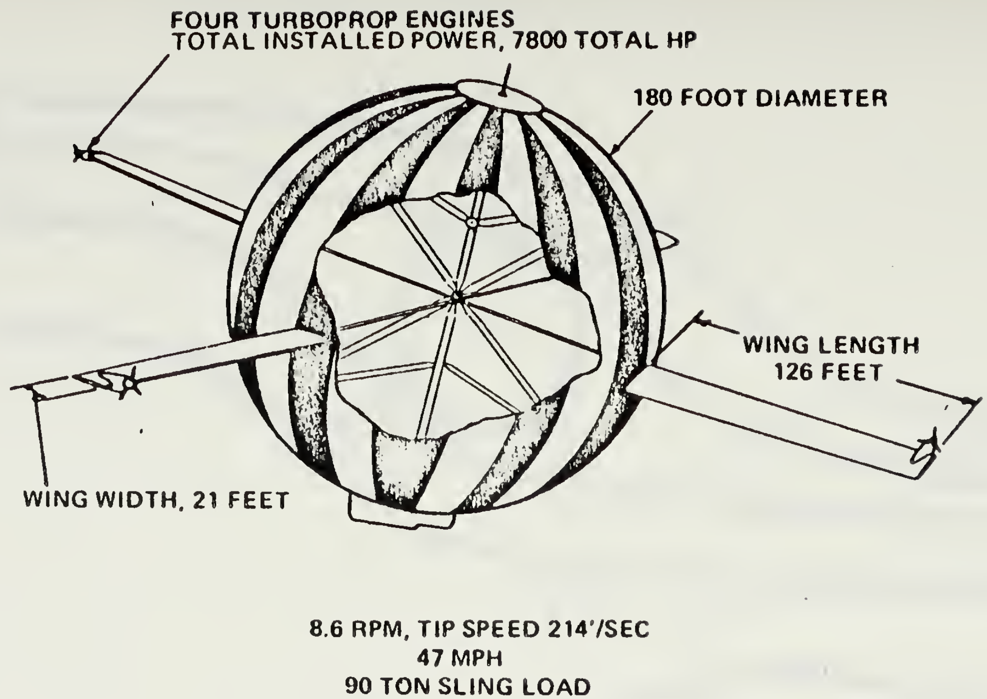

Figure 14. The Aerocrane (Artist's Concept).
Source: Massachusetts Institute of Technology, Interagency Workshop on Lighter-than-Air Vehicles, "Lots" of LTA Applications.

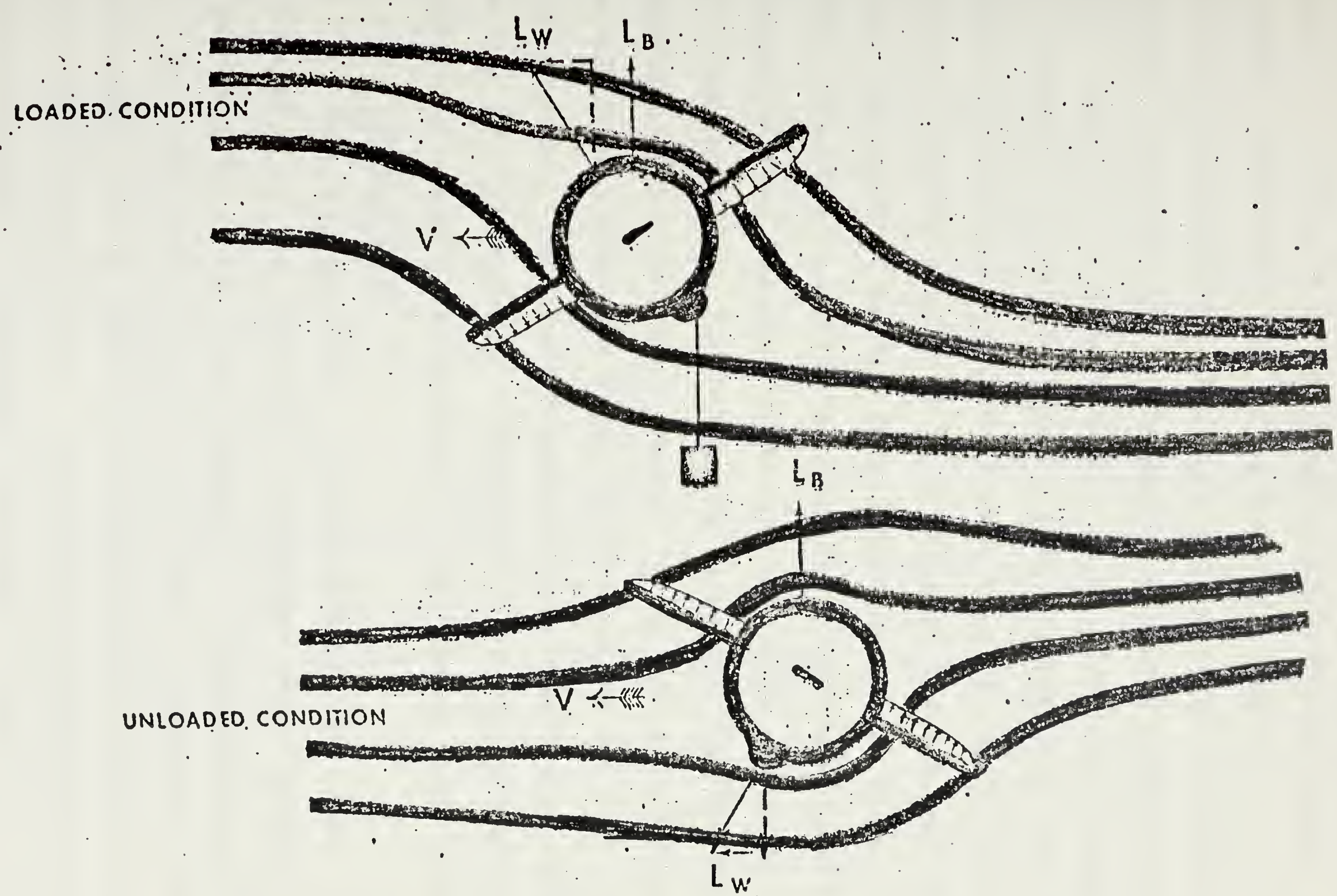

Figure 15. The Aerocrane Flight Dynamics.
Source: Commander, Naval Air Systems Command, Ltr 03832 Dated October 6, 1975. Subject, Aerocrane (Enclosure 1).

buoyant air vehicle which employs four large helicopters rigidly attached to an interconnecting structure with their controls interconnected. A helium-filled envelope is attached to the interconnecting structure and is sized to provide almost all the buoyance to the entire assembly (Figures 16, 17) (24). In this configuration the helicopter rotor's thrust can be used entirely for useful lift, multiplying the individual helicoptor's useful load more than ten times (24). A "heavy" buoyancy condition is maintained for all regimes of flight in order to permit VTOL operation at all times, even under no-payload conditions, thus avoiding the necessity for payload/ballast transfer as is the case with naturally buoyant airships (27). The helicopter's control systems are interconnected so that they respond to one set of controls in the aft port helicopter which is designed as the master control station. This interconnection is accomplished through the use of "Fly-by-Wire" technology (24). The payload is carried externally slung below the vehicle on four cables.

3. Air Summary

The "air solution" is uncertain at this time. The development of the Army HLH, if resumed, would increase the lift capacity of the U.S. helicopter to approximately 22-23 tons. This lift would be sufficient to carry all 20-foot containers, but it would be insufficient for larger containers or some hatch covers. Although the technology required may be available to develop a helicopter to lift up to 35-45 tons, a capability of lifting greater weights of up to 75 tons with a helicopter is probably far more speculative.

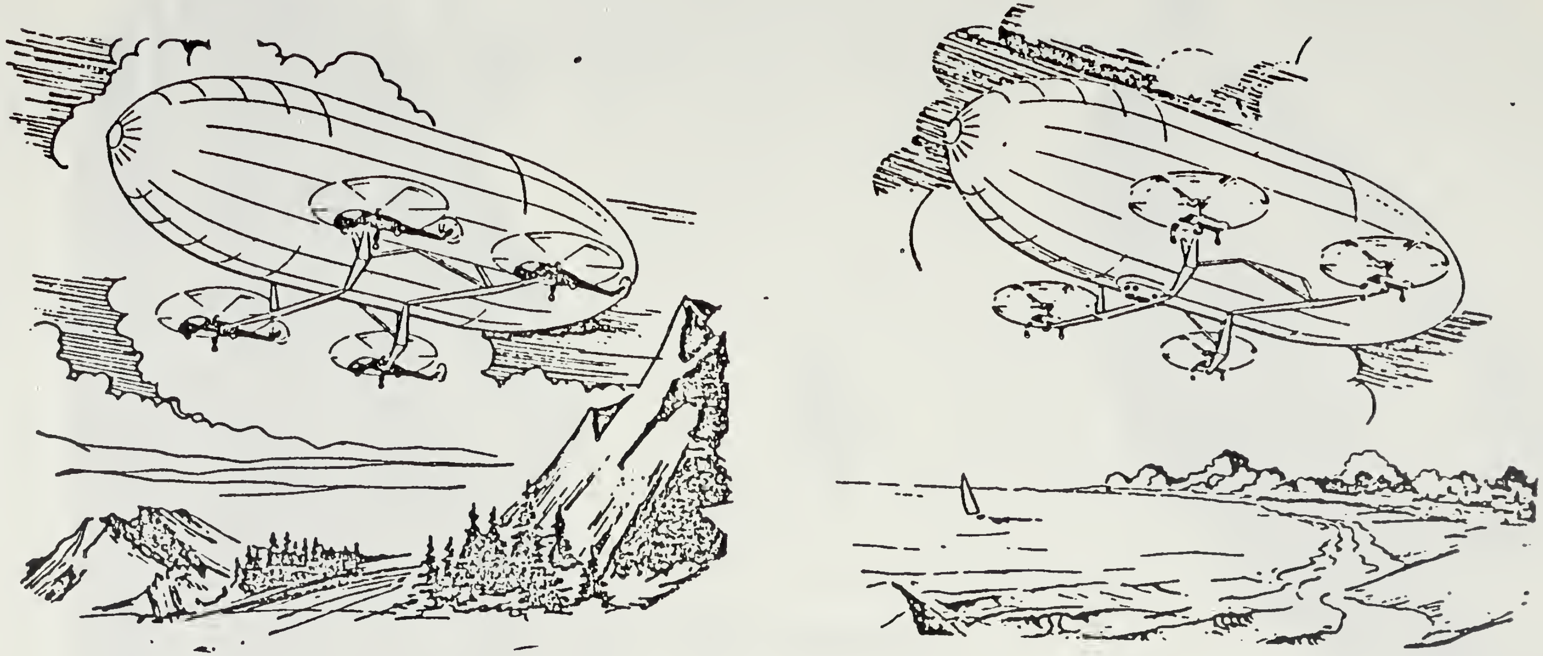

Figure 16. The "Hybrid" Airship, The Heavy Lift Airship Vehicle.
Source: Goodyear Aerospace Corporation, Feasibility Study of Modern Airships.

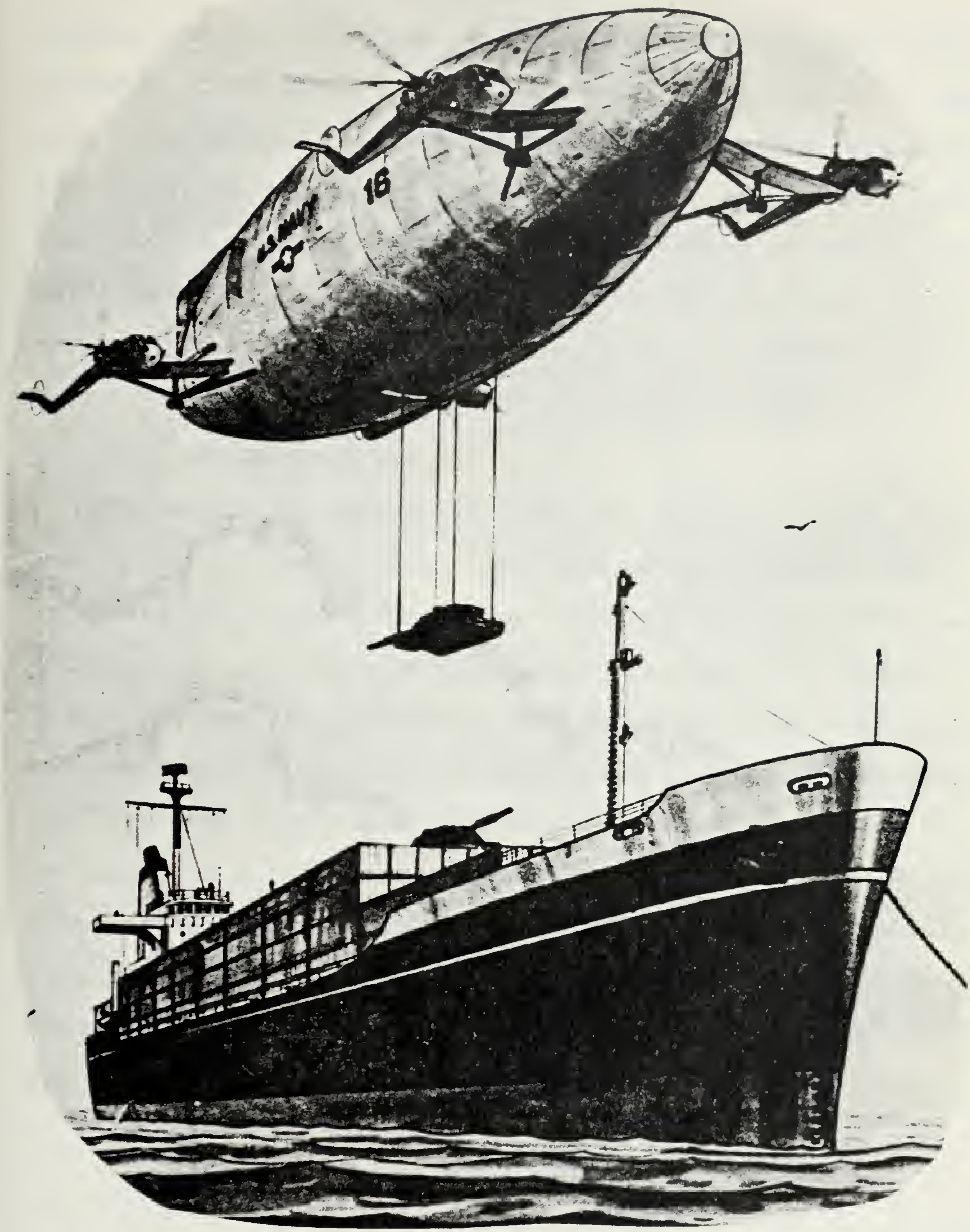

Figure 17. Artist's Concept of Helistat in Logistics-over-the-Shore (LOTS) Application.
Source: Piasecki Aircraft Corporation, Helistat Ultra Heavy Vertical Airlift System Model 97-1C.

Studies and model testing of the Aerocrane and Helistat have indicated that these systems must still be considered a high-risk development. These semibuoyant hybrid craft may, when developed, be capable of meeting the short haul, heavy lift operational requirements. The limited degree of testing and development of the concepts suggest that considerable more study and testing will be required before a judgment can be made as to their ultimate feasibility and utility.

H. SURFACE/AIR SOLUTION

The remaining alternative does not neatly fit into the surface or air categories. This system is a unique blend of the reliable winch technology from the surface lift components and the economic heavy lift advantages of lighter-than-air technology. This system, developed from technology originating in the logging industry and illustrated in Figure 18 (28), uses a nonrigid balloon to lift containers out of the holds of a containership and place them ashore. It has been tested with a positive degree of success, and further development may prove it to be one of the most economical and reliable systems yet attempted with the non-self-sustaining containership (29).

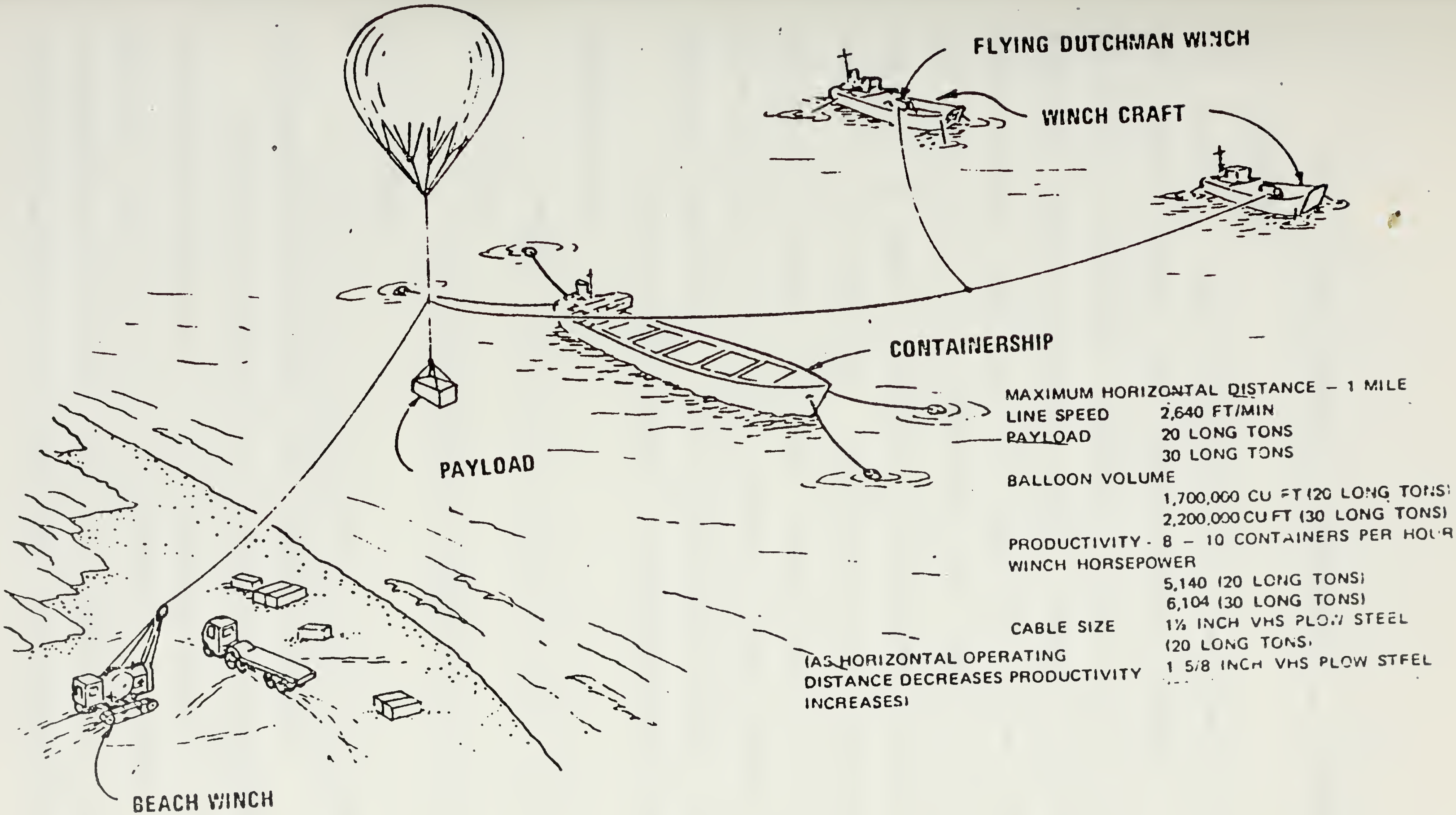

Figure 18. The Balloon Discharge System.
Source: Air Force Range Measurements Laboratory, Balloon Feasibility Study.

III. LIGHTER-THAN-AIR TECHNOLOGY: A REVIEW

A. BACKGROUND

In recent years there has been a resurgence of interest in buoyant airships and lighter-than-air flight. Formerly, interest in the great airships occurred and reoccurred in somewhat cyclical patterns; today, however, with increasing environmental pressures and rising fuel costs, enthusiasm and interest in the lighter-than-air vehicle as a possible solution to some of tomorrow's transportation problems has assumed a new dimension. Rising fuel costs and dwindling supplies of energy have drawn fresh attention to the attractive possibilities of the appropriate application of lighter-than-air principles. These principles include (30):

1. A minimal dependence on prepared facilities and rights-of-way.

2. A unique ability to transport large, heavy loads at low cost.

3. An unequalled airborne endurance both on station and en route.

4. A short haul transportation system with low fuel consumption and minimal environmental impact.

These characteristics are particularly relevant in view of rising energy costs: an airship or balloon can overcome gravity with virtually no expenditure of energy. Energy consumption is required only for propulsion and maneuvering, thereby opening up the possibility of transporting large,

heavy loads with minimal fuel consumption, and, at the same time, enjoying the desireable environmental by-products of low noise and pollution levels.

The possible applications to transportation of this technology are almost limitless. At a recent Interagency Workshop on Lighter-than-Air Vehicles organized by the Massachusetts Institute of Technology, over 150 separate papers on the subject were presented and seriously considered by the group. Each of these ideas had a unique twist which sought to provide a solution to harnessing the great lighter-than-air potential. Subsequent to this conference, an assessment of lighter-than-air technology was developed by Joseph F. Vittek, Jr. of the MIT Flight Laboratory (30). The various ideas were given due consideration and, while many were found worthy of further investigation, only one concept, the tethered balloon, was found to be successful in today's commercial world. Only this application of the lighter-than-air technology offered immediate, practical possibilities for solving the very short haul transportation problems of tomorrow.

B. DEFINITIONS

1. General Classifications: Heavier-than-Air and Lighter-than-Air

Before investigating the current balloon transport systems in detail, it would be useful to define some aeronautical terms and concepts. Aeronautics implies both heavier-than-air aircraft (HTA) and lighter-than-air aircraft (LTA). The HTA derive their lift from aerodynamic

qualities, whereas LTA derive their lift aerostatically from the displacement of air. The HTA have only aerodynamic lift, but LTA not only have buoyancy, but can also, by flying at slight inclinations, generate an aerodynamic lift as well.

2. <u>Heavier-than-Air Aircraft</u>

Heavier-than-air aircraft are placed in two fields or classifications: the "fixed wing" and the "rotary wing" types. Virtually all military officers understand the basic differences between these two types of aircraft, and most also at least vaguely understand the rudiments of the economics and problems associated with them.

3. <u>Lighter-than-Air Aircraft</u>

On the other hand, in the LTA field few people other than lighter-than-air enthusiasts and aerodynamic engineers understand the various existing classifications, and fewer still understand the economics and possibilities associated with the various concepts. The simplest forms are "free" and "captive" balloons with buoyant lift only. When the balloons are given their own means of propulsion, they become maneuverable and are called dirigible balloons, airships, or simply dirigibles. Usually this usage connotates the rigid airship; i.e., a balloon with a rigid internal framework, although technically the term could be accurately applied to a rigid, a semi-rigid, or a non-rigid blimp or airship. Commonly, the dirigible is also referred to as a zeppelin, although the zeppelin is actually a particular type of airship produced by the Zeppelin Company in the

[illegible]

same manner in which the well-known 747 is a Boeing 747 (31).

4. Hybrids

If a dirigible-type airship is designed with features combining substantial aerodynamic lift with buoyant lift, the vehicular devices must either make a takeoff run to generate airfoil lift or use vertical thrust and/or rotary wing configuration to achieve vertical takeoff capability and maneuverability. This type of airship is called a "hybrid". Although several small-scale hybrids have been successfully designed and demonstrated, their full-scale prototype has yet to be constructed and proven. Therefore, little is really known about the hybrids, and at present they may or may not have real economic potential.

5. The Tethered Balloon

Finally, there is the tethered balloon -- a simple captive balloon controlled by cables attached to the ground and incapable of free flight. The tethered balloon is often considered a part of the LTA world when, essentially, it is a different concept and should be distinct from the dirigible, zeppelin, hybrid, and free balloon concepts. In illustration, there is the airship/surface ship analogy: in normal operation an airship (dirigible, zeppelin, or hybrid) is not really lighter than air; like a surface ship, it is equal in weight to the air it displaces. Free balloons and all airships should be more accurately termed buoyant aircraft, and the term lighter-than-air should not be applied to them at all. Only captive balloons operate in a truly lighter-than-air method and these captive, or tethered,

balloons are free of most of the problems that almost eliminated and will always hamper the development of the buoyant aircraft.

C. HISTORICAL REVIEW

1. Military Utilization

Ever since November 21, 1783 when Francois Pilatre de Rozier and Marquis Francois Laurent d'Arlandes arose from Paris in a hot air balloon, the whole idea of lighter-than-air flight has fascinated men, and as early as 1794, balloons were used for military purposes. During the war with the Austrians and the Dutch, the French used a tethered balloon for observation during the Battle of Fleuras, and at the Battle of Maubuque, use of the French balloon Entreprenant quickly resulted in the surrender of the beseiged city of Charleroi. Balloon observations had provided General Jourdan with the location of all enemy troops and equipment, and there was no escaping the aerial observer (32). The balloon thus allowed generals to take advantage of "near real time information" during a battle, thereby overcoming one of the most serious limitations in early warfare. Now the battlefield commander could monitor the enemy as well as his own forces. The use of these observation balloons continued in Europe through the First World War, when they were used to direct artillery fire onto enemy tanks (32).

In the United States the first military application of the balloon occurred in 1861 during the Civil War, when the Union Army made use of balloons as observation platforms (32).

2. Zeppelins

a. Military Development

Although it is possible to trace the adventures of such early balloon pioneers as Henry Gifford, who made the first true airship flight in 1852, or Charles Renard and Captain A.C. Krebs (32), it would not be productive to do so since no significant activity resulted from lighter-than-air flight until Count Ferdinand Von Zeppelin and the Schutte-Lanz Company combined resources in 1915 to develop the L-30 class dirigible or "super Zeppelin" (33). This alliance, first successful in peacetime, was amplified by wartime pressures and produced airships which were used by the Germans during World War I for raids on Allied cities and war vessels. France and Great Britain also built airships for wartime use, and the sophistication (in relation to the technology of the day) of these early war-inspired airships is little appreciated today. At their zenith, before improved antiaircraft and fixed-wing aircraft armed with incendiary bullets forced the hydrogen-filled airships from the British skies, the Zeppelins were capable of operating at 20,000 feet with 40-ton bomb payloads (34).

The World War I use of Zeppelins was a tremendous success for the Germans because with little outlay of actual economic resources, they forced the Allies into a heavy resource commitment to the defense and thus tied up funds, equipment, and manpower which the British could have used elsewhere. Therefore, even its first significant application, the dirigible was an economic success.

b. Conversion to Civilian Usage

After the war the Zeppelin Company quickly adapted the war-inspired technology to peacetime use, built two airships, and instituted airship passenger service within Germany. This early effort was stopped by the Allies who confiscated all airships in Germany and transferred them to other Allied nations. This act might well have terminated the construction of buoyant airships if the United States had not been left out of the Zeppelin distribution and later successfully negotiated a contract for an airship from the Zeppelin air works. The construction of this airship, later known as the Los Angeles, kept the Zeppelin Company alive until production restrictions were lifted in 1925 (30).

The Zeppelin Company was then allowed to proceed with unlimited construction and to build one of the world's largest and most successful lighter-than-air passenger fleets. The most successful airship ever built was the Graf Zeppelin, which made 590 flights, flew over 1 million miles, and spent 17,000 hours in the air. In addition to being in regular service on the South American route, it completed the only round-the-world voyage ever made by an airship and ended its life peacefully when scrapped in 1940 -- twelve years after entering service.

The largest and most notorious airship ever built, the German LZ-129, the Hindenburg, was completed in 1936, was 811 feet long, and had a gas volume of 7,063,000 cubic feet. Its cruising range at 78 miles per hour was 8,750 miles, and it was powered by four 4000-horsepower diesel engines.

It was originally designed to use helium as a lifting agent; however, when the American government refused to sell helium to Nazi Germany, highly flammable hydrogen was substituted (35). In May, 1937, after its 37th transatlantic flight, the Hindenburg exploded and crashed at Lakehurst, New Jersey. Although the Hindenburg disaster was only one more in a series of disasters which plagued the infant airship industry, its spectacular nature and thorough coverage by the news media so marked the psychological culture of America, it essentially ended the era of the airship, leaving an impact concerning airship safety and reliability that lingers today. It may be of interest to note that the loss of the Hindenburg was the first instance of passenger injury or fatality in the entire German commercial lighter-than-air service (36).

D. PAST PROBLEMS

1. Public Acceptance

The idea of lighter-than-air flight must be accepted by the general public as a practical tool or solution if the present enthusiasm surrounding the concept is to be maintained. Historically, the prevailing attitude in American society concerning lighter-than-air flight has been the belief that it is fundamentally unsafe. This lack of basic confidence in the buoyant airship concept probably relates to the spectacular airship crashes cuased by violent weather and inexperience in the first four decades of this century. Furthermore, it is unlikely that general public attitudes concerning airship safety will change until solid

evidence can be presented to the contrary. Until then, general acceptance of the practical LTA concepts remains in jeopardy.

This unease about the safety and practicality of buoyany airships and LTA concepts unfortunately creates a host of skeptics who generalize and oversimplify the problems of lighter-than-air flight. The demise of the airship did not simply result from safety considerations stemming from crashes such as the Hindenburg. The airship concept was also beset with a number of real problems which must be solved if the concept is to prove valid and economically feasible. Airship enthusiasts often either treat these problems as nonexistant, or they highly underestimate them. The general public is usually unaware of them, and not many of the men who actually confronted these problems in the golden era of the Zeppelin are around to define their unusual nature. Fortunately, Walter P. Maiersperger, in a paper titled "Design Aspects of Zeppelin Operations from Case Histories" presented to the Interagency Workshop on Lighter-than-Air Vehicles in 1975, documented these problems so that practical men could understand what the enthusiasts of popular literature normally failed to address. The following summaries are from this paper, and they attempt to realistically present the case against the resurgence of buoyant airships on an economical basis (35).

2. Aerostatics

Misunderstanding concerning balloon flight dates back to the late 1700's when the French government attempted to

reassure its people of the safety of balloon experimentation then in progress with a proclamation explaining the operating principle of the balloon: "...filled with an inflammable air a balloon will rise toward heaven until it is in equilibrium with the surrounding air". Ever since this unfortunate statement, all too many people believe that a balloon will rise until it is in equilibrium with less dense air at higher altitudes, and conversely, that a balloon will sink until it is in equilibrium with lower, more dense air. In fact, aerostatic lift is an unstable lift. A light balloon will go up until the pilot valves off gas, and a heavy one will go down until the pilot drops weight. Failing to drop weight means that a balloon will go down until it hits earth, and failing to valve off gas means that a balloon will go up until it bursts (with newer, stronger surface materials, however, it will stay in equilibrium until gas is valved off). These simplified physical facts are responsible for the expenditure of both gas and ballast on every flight. "In operation, an airship must sacrifice almost one per cent of its gross lift for every 100-foot rise in altitude, and must carry a minimum of three per cent of its gross lift in the form of ballast to prevent inadvertant descent at inopportune times. In practice, its lifting gas is assumed to be about 95% pure (i.e., diffused by five per cent air). Thus, a commercial airship must sacrifice about 13% of its cargo capacity to fly at minimum altitude (1500 feet) with minimum safe ballast." (35) This is an economic constraint no other trans-

portation vehicle faces.

Regulations for scheduled instrumented flight would require a minimum cruising altitude of 8000 feet over the eastern United States and of 16,000 feet over the western United States. An airship designed for transcontinental flight would therefore face a maximization of the valve off gas-ballast problem, and, as a result, its economic possibilities would be proportionately decreased. It is for this reason that an analysis of airship passenger routes of the past reveals a large number of transoceanic routes at low altitudes and few transcontinental routes. It may also explain why only one airship ever flew all the way around the world. None of the historic transcontinental flights over the United States would be sanctioned today under modern air regulations, yet these flights are continually recalled by balloon enthusiasts to validate the capabilities of the Zeppelins as passenger transportation systems.

3. Superheat

The superheat condition refers to the amount of increase in gas temperature above the surrounding air. Superheat develops most noticeably when the airship is moored on an airfield during a sunny day, and the problem can be greatly amplified in alternating conditions of rain and sunshine. Assuming that an airship is moored in a city at elevation "1675 feet, the airship will be at 7,400 feet density altitude if 40°F of superheat is allowed to develop on a 100°F day. A sea level design airship with full cells will blow

off gas equivalent to 18 % of its gross lift" (35). because of the heat-caused expansion of the inflation gas. This condition occurred when the Graf was moored at Los Angeles and very nearly resulted in disaster. There are a number of other documented cases where disaster or near disaster resulted form the superheat condition (32). Larger dirigibles would require an airfield to have inflation gas, water, and fuel-pumping facilities to maintain the airships at correct equilibrium under changing conditions, implying that large dirigibles may not have the amount of flexibility that popular literature would lead one to believe.

4. Weather

a. Rain, Snow, and Ice

Rain, snow, and ice loads create unanticipated problems by adding weight and/or freezing controls, and both have been causes of past Zeppelin disasters. When extra gas is added to allow take-off with loads of rain, snow, or ice on the cover, this gas must be blown off when the ship reaches operating altitude. Cold weather would normally allow take-off. Rain loads have created conditions where the gas cells were completely filled before lift capability was achieved.

b. Storms

Although the problems of valving off gas or tossing ballast can be solved by several alternative systems that compress gas internally or recover weight lost in fuel consumption by extracting water from exhaust systems, these systems may be practically developed for normal weather condi-

tions, but they might not maintain the necessary degree of control in the violent atmospheric conditions of storms. An oversimplified answer is to avoid such conditions, but, as all mariners know, this is not always possible. If an airship is to be feasible, it would be desireable to have alternative landing and mooring sites or systems to allow its survival in the storm conditions that will inevitably be encountered.

5. Temperature Variance

Airships moving into warmer air tend to sink until their gas temperature normalizes with the surrounding air. The reverse is true if the ship encounters cooler air. The airship, therefore, must proceed cautiously while moving from one air layer to another. The Ayron, for example, spent several hours cooling off before descending into San Diego on her first trip West. Clearly, scheduling the airships becomes difficult. Steamship schedules are usually accurate to the early or late tide; airplane and train schedules are often accurate to the minute; but airship schedules never attempted accuracy beyond the day of arrival or departure, a factor which must be taken into consideration.

E. OTHER CONSIDERATIONS

1. Myths

The airship idea is often clouded by several widely-held beliefs which, while not entirely untrue, are sufficiently confusing to attribute imaginary characteristics to airships which do not entirely correlate with real facts.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Most of this confusion surrounds the word "airship", an unfortunate choice of names. It implies that attributes associated with surface ships can also be applied to airships. It has been suggested, for example, that airship lift can be made safer by being subdivided into multiple compartments in much the same manner as the surface ship. An airship, therefore, could lose one or more compartments without endangering the airworthiness of the ship. Actually, this compartmentalizing feature would only delay disaster, not prevent it. To remain aloft the airship must jettison weight equal to the lifting capacity lost by deflating cells or compartments. If it cannot do so, it will sink to earth, and if it does not jettison so as to maintain satisfactory trim, it may remain aloft but without a means to control itself. In either case, the probability of the ship reaching safety is minimal.

Furthermore, shipping via surface waterborne vessels is the cheapest and best mode of long distance transportation known to man, but it does not automatically follow that airships which are also buoyant vessels, are potentially comparable cargo carriers. Even the most inexperienced transportation officer knows that, generally speaking, it is the cube of the cargo that can be placed inside a surface vessel that is the limiting factor, not the weight of the cargo that affects the stability of the surface vessel. In contrast, the passenger and cargo space on the airships of yesteryear were so small as to be almost unrecognizable, and weight was always the constraining factor.

2. <u>Airship Construction</u>

Most balloon enthusiasts agree that building an airship with the operating characteristics necessary to compete in specified freight markets can be accomplished with the current techniques available. There are several creditable studies available (37, 38, 39, 40, 41, 42, 43, 44, 45, 46) to substantiate this belief; however, these studies appear to include only direct manufacturing costs in their analyses and do not add all the overhead costs involved in the manufacturing process.

Because of the immense size of airships, the hangar and assembly facilities required to construct an airship are not available at present, and the construction of such facilities would represent a sizeable investment for any potential airship manufacturer. Allocation of such costs to the limited numbers of airships built would greatly increase the sale price. Without federal assistance, it would become difficult to find a buyer for a large enough quantity of airships to absorb these costs at reasonable levels, particularly when the market being serviced is uncertain and speculative.

3. <u>Helium Availability</u>

Preliminary investigation into the availability of helium reveals that it is a dwindling resource and its availability is limited. Helium occurs in underground deposits as a constituent of either natural gas (about 95%) or a noncombustible gas, usually nitrogen. In 1960 the Bureau of Mines estimated that the total helium resource of the United

States in helium-bearing natural gas was 196 billion cubic feet. Furthermore, they estimated that natural gas fields are being depleted at such a rate that helium recovery after 1985 will probably not be enough to supply the demand beyond that time (47).

With the passage of the Helium Act Amendments of 1960, authority was given to the Bureau of Mines to execute contracts for the recovery of helium by private firms, and for its delivery to government-owned pipelines for transportation to an underground storage facility in Cliffside, Texas. This program allowed the extraction and recovery of the helium in natural gas which would otherwise have been lost through the use of natural gas as a fuel. As a result of this Act, the government became obligated to sell helium to consumers at a price which would make the program self-sustaining over a 25-year period (48). At the present time helium is being produced at twice the consumption rate (28).

F. PRACTICALITY

In spite of the commercial successes experienced during the 1920's and -30's by the Zeppelin Company and its competitors, there were very real problems which defeated the airship as a practical transportation mode. Based on performance, the record of buoyant aircraft such as the dirigibles and Zeppelins was so discouraging that it lead to their eventual abandonment. The hybrid is an attempt to revive this technology in a new dimension, but it has yet to be proven practical. The question now revolves around the issue of

whether new materials, power plants, computational methods, control systems, or concept combinations can change the situation and make these buoyant airships more successful than they were in the past. While most of the problems outlined in Section D do have solutions using today's modern technology, it is still very likely that the problems of inherent bulk, low power, slow speed, altitude limitations, and high manufacturing costs may combine to present too many difficulties to be overcome easily in the foreseeable future. This recognition of the possible limitations surrounding buoyant airships should not lead to the conclusion that lighter-than-air transportation applications are impractical. Rather it should lead to better understanding of the actual potential of LTA to various applications and other technological and economic breakthroughs. Practically speaking, the only LTA technology available today with proven, demonstrated success is the tethered balloon.

G. TETHERED BALLOONS

1. Use of Tethered Balloons for Military Purposes

The reluctance of most military officers to accept the idea of a practical and economical tethered balloon system and to separate it from the concepts associated with buoyant or hybrid aircraft is probably attributable to an unfamiliarity with modern balloon systems and an association of balloons with the buoyant air platforms of a bygone era. Typical attitudes and associated arguments are usually based on misunderstandings which label all balloons as un-

safe, unstable, and unnecessary. Unfortunately, this attitude either ignores or dismisses accounts of a number of highly successful commercial and military applications which use the controlled aerostatic lift of the tethered balloon to perform a variety of useful functions.

The use of tethered balloons is not an entirely new idea. As previously stated, the French Army used tethered balloons as early as 1794 to provide its generals with real time information concerning the movement of enemy troops (32). Their use as platforms for observation purposes continued throughout the history of warfare and reached a peak during World War I when they were routinely used on the western front by the French to direct artillery fire. During World War II they were used for antiaircraft defense over British cities and were termed barrage balloons (32).

Although the balloons and the observation methods have changed over the years, the use of tethered balloons for observation purposes has remained with the military. Observation devices suspended from high altitude tethered balloons were used in Vietnam to monitor North Vietnamese troop and logistic movements, and these same devices are in routine daily use along the 38th parallel in Korea.

2. Use of Tethered Balloons for Scientific Purposes

The most common and familiar use of the tethered balloon has been for scientific purposes in the meteorological field. From almost the very beginning of lighter-than-air flight, man has been using balloons for this purpose. In September, 1784, some seventeen months after the

first manned flight and four months before they crossed the English Channel in a manned free balloon flight, Jean Pierre Blanchard and Dr. John Jeffries took barometric, thermostatic, and hygrometric measurements from a tethered balloon platform (49). From such modest beginnings the use of scientific ballooning has progressed to the point where they are in almost constant use for this purpose, and the majority of information available concerning tethered balloons involves their use for scientific purposes.

3. <u>Use of Tethered Balloons for Commercial Purposes</u>

Today the most notable strictly commercial use of the tethered balloon as a stable, high altitude platform is found in the communications industry. The Bahamas Islands use a high altitude tethered balloon system to receive relayed commercial television and radio signals. This system was installed several years ago at a cost of approximately one million dollars which included the all-weather aerostatic winches and accessories. It has operated continuously on a profitable basis (30).

4. <u>Development of the Commercial Balloon Transport System</u>

Chester Mathieson is credited as the first man to attempt to use the balloon as a method of transporting heavy objects from one place to another (50). In the early 1960's Mathieson obtained a World War II barrage balloon and a cable and winching system with which to experiment. Unfortunately, the aerostatic lifting capability of the 50,000 cubic-foot barrage balloon was too low to lift heavy

loads efficiently. To improve the lifting capabilities, Mathieson tried to add aerodynamic lift from the motion of the aerodynamically-shaped balloon. While the payload was lying on the ground, the barrage balloon was backed to a position well aft of the load, and, in the words of one eyewitness, "Mathieson gave it a hell of a pull" (50). Theoretically, by the time the balloon was over the payload, the balloon would have accelerated to the velocity at which the combined aerodynamic and aerostatic lifts were sufficient to carry the payload. The resulting system did work and was interesting; its reliability, however, was questionable.

In an attempt to increase the reliability of these first efforts, vee balloons, consisting of two cigar-shaped hulls connected at the nose and spreading to a vee in the rear with a fabric membrane in the center plane, were investigated for lifting heavy payloads. Although the vee balloons had greater aerodynamic lift, they encountered much the same problems that had plagued the barrage balloons. The winds generally were not cooperative in either speed or direction, and it was necessary to have relative motion prior to pick-up to achieve the necessary lifting capability. A final condemning factor in the vee balloons was the necessity to change orientation and point the balloon into the relative wind as it changed its direction of motion. This requirement led to time-consuming gyrations of the balloon and, eventually, abandonment of these efforts to utilize tethered balloons to move heavy loads from point to point.

In the mid-1960's the Raven Industries, Inc. of Sioux Falls, South Dakota, a balloon manufacturer, began serious investigation into the possibility of using a tethered balloon system to remove felled logs from remote areas that would have otherwise been inaccessible (51). These remote sites were for the most part canyons, ravines, and hilly terrain where road construction costs were prohibitively expensive and damage incurred to the surrounding terrain from skidding with ground level winch and cable assemblies during normal logging operations resulted in unacceptable levels of erosion or stream pollution. If, however, a method of removing these felled trees profitably could be developed, formerly worthless timber would suddenly have real value.

With this incentive in mind, several studies were conducted which indicated that the idea of using spherical tethered balloons to lift these trees out of the inaccessible areas had real, practical value. Onsite experiments conducted by the Bohemia Lumber Company further confirmed the validity of this concept. In late 1965 an informal testing and development program was undertaken by this company to determine the optimal balloon design for the proposed system. Essentially, at that time (1965) the available choices were: either natural-shaped (inverted teardrop) balloons, produced for this purpose by the Raven Industries, or non-rigid, aerodynamically-shaped balloons with "Y"-shaped empennages (tail assembly) similar to the balloons used as

barrage balloons in World War II (these had been previously tried with negative results).

At equal envelope volumes, and thus equal aerostatic lift capability, the aerodynamically-shaped balloon had the natural advantage of a lower coefficient of drag when nosed into the wind or hauled rapidly along a predetermined path.[1] This advantage indicated that the aerodynamically-shaped balloon would require much less horsepower in the winch assemblies to control it accurately and that it could attain faster speeds when being hauled between points. In spite of these natural advantages, however, changing, low-altitude crosswinds at ground level created unstable conditions in the aerodynamically-shaped balloon and caused erratic motions and lift which were difficult to predict and for which it was difficult to compensate. To overcome this erratic action and to avoid lost cycle time required for "weathercocking" (swinging the aerodynamically-shaped balloon around at the end of each run), the natural-shaped balloon was selected as the optimal choice for the short distances involved in the developing balloon transport system. In spite of the high coefficient of drag inherent in the natural-shaped balloon, the associated increase in winch horsepower requirements, and lower operating speeds, experience in the field indicated that the natural shape presented the same size and shape in all horizontal directions so that it could be moved in either direction with predictable results. For the bal-

1 See Appendix I: Coefficient of drag aspects for aerodynamically-shaped and natural-shaped balloons.

loon transport system being developed, this meant better stability, more control, and faster cycle times. By 1967 economically profitable operations were being conducted, and the evolution of the balloon transport system had begun (51).

IV. THE TETHERED BALLOON TRANSPORT SYSTEM

A. THE BASIC SYSTEM

1. Components

The tethered balloon transport system has evolved over the last ten years into a highly developed system of proven reliability. Figure 19 shows the layout and the components of a typical system currently being used in the logging industry. The central components are: the balloon; four wire rope-control cables (balloon tether line, load line, main line, and haulback line); a large, self-propelled winch assembly mounted on a caterpillar-like tractor frame (a yarder, Figure 20); and several ground-mounted sheaves (trail blocks) which complete the hardware necessary to operate the system. The point at which the four cables meet is called the confluence point.

2. Operation

In normal operation the balloon flies at an average altitude between 400 and 500 feet, and it moves payloads (logs) over various distances up to a maximum of 3600 feet. The balloon provides the lift to support both the payload and the cables.

Inasmuch as the tethered balloon operates in a truly lighter-than-air mode, the release of the payload creates an upward force equal to that of the payload, and, therefore, the balloon as well as the cables and yarders must be capable of controlling this lift force. The yarders

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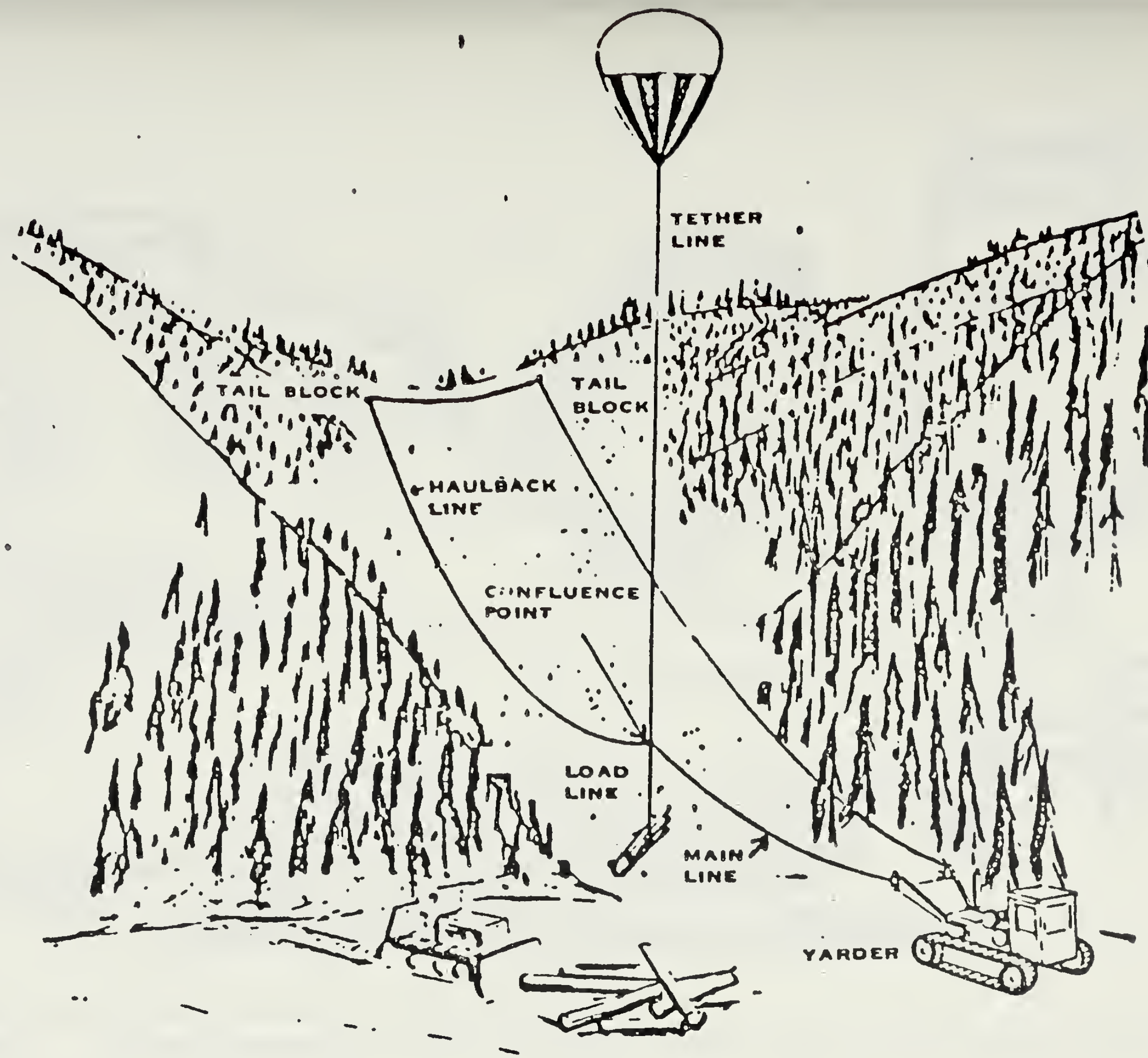


Figure 19. Typical Logging Layout.
Source: Air Force Range Measurements Laboratory, Balloon Feasibility Study.

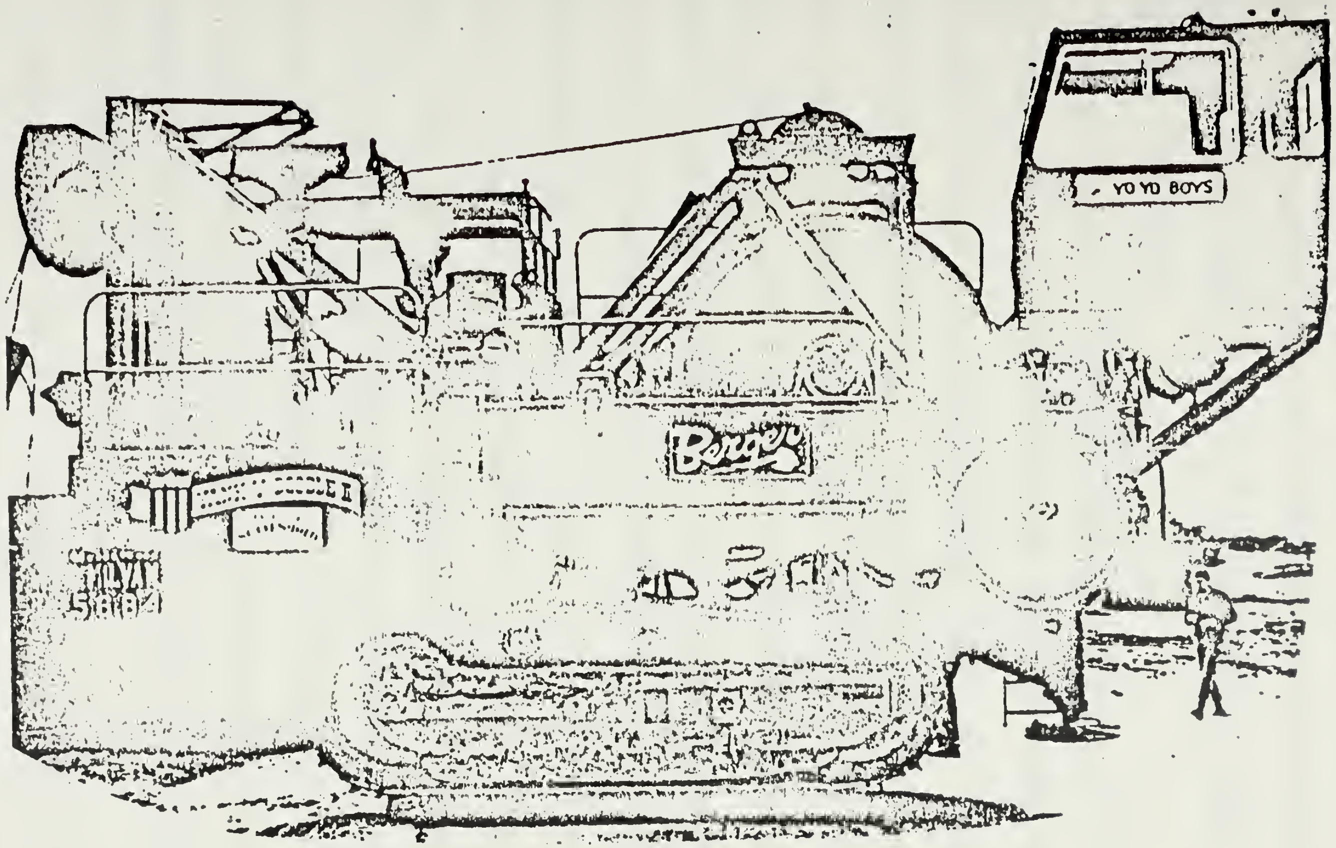


Figure 20. Balloon Transport System Yarder.
Source: Joint Army-Navy Balloon Transport System Test, Preliminary Report.

are heavy machines and are often either ballasted with additional weight or anchored to insure that they remain stationary. For safety and to prevent the escape of the balloon, the tether between the confluence point and the balloon attachment point is a double cable composed of two parallel wire ropes, each independently capable of controlling the balloon.

The main and haulback lines provide control for the vertical height of the balloon as well as pull the balloon back and forth across a predetermined path established by the locations of the sheaves. The main line runs directly to a winch on the yarder, and the haulback line runs away from the yarder through a series of blocks and back to a separate winch on the same yarder. These two yarder-mounted winches operate at speeds of up to 2400 feet per minute and can be independently controlled in order to maneuver the balloon with or without its payload, as desired. In actual operation, when one winch is reeled out and the other is reeled in, the balloon and the payload are moved back and forth across the predetermined path (Figure 19). If both winches are reeled in or out in the same direction, the balloon (assuming equal winch speed in both winches) is moved directly up or down vertically.

The maximum lateral transport distance possible in the system as presently used is determined by the length of cable that can be placed on and controlled by the yarder winch drums. This distance, as previously stated, is a maximum of 3600 feet; however, normal operations usually do not exceed

a distance of one-half mile.

Once the sheaves have been located in the desired position, the cable track is initially set up with a lightweight straw line (in nautical terms, a messenger) which allows the one-inch steel cable to be threaded through the sheave and block assembly using the power of the yarder winches. Relocation of the layout inside a given working area is easily performed by reeling in the balloon until it is directly over the yarder, leaving the cable assemblage slack. In this condition the sheaves can be moved as desired.

3. Capability

In its present configuration the system uses a 530,000 cubic-foot balloon which has a lift of approximately 25,000 pounds at sea level. The average transportation payload is 22,000 pounds, a figure arrived at by subtracting average cable weight and adding a safety factor. Cycle time for the system varies between five and eight minutes, depending on lateral distance and wind conditions.

Balloon logging operations (yarding) are conducted in winds of 25 miles per hour. Individual balloons have survived 80 mile per hour winds when moored in previously prepared bedding areas where the balloon is tightly secured to the ground with an anchor system (Figures 21 and 22).

Relocation of the entire system is easily accomplished. Yarders (measuring 16 feet high, 12 1/3 feet wide, and 30 feet long) are track-mounted and can be moved short distances under their own power. Longer hauls can be made by loading the yarders on low-boy trailers. The balloon is moved while

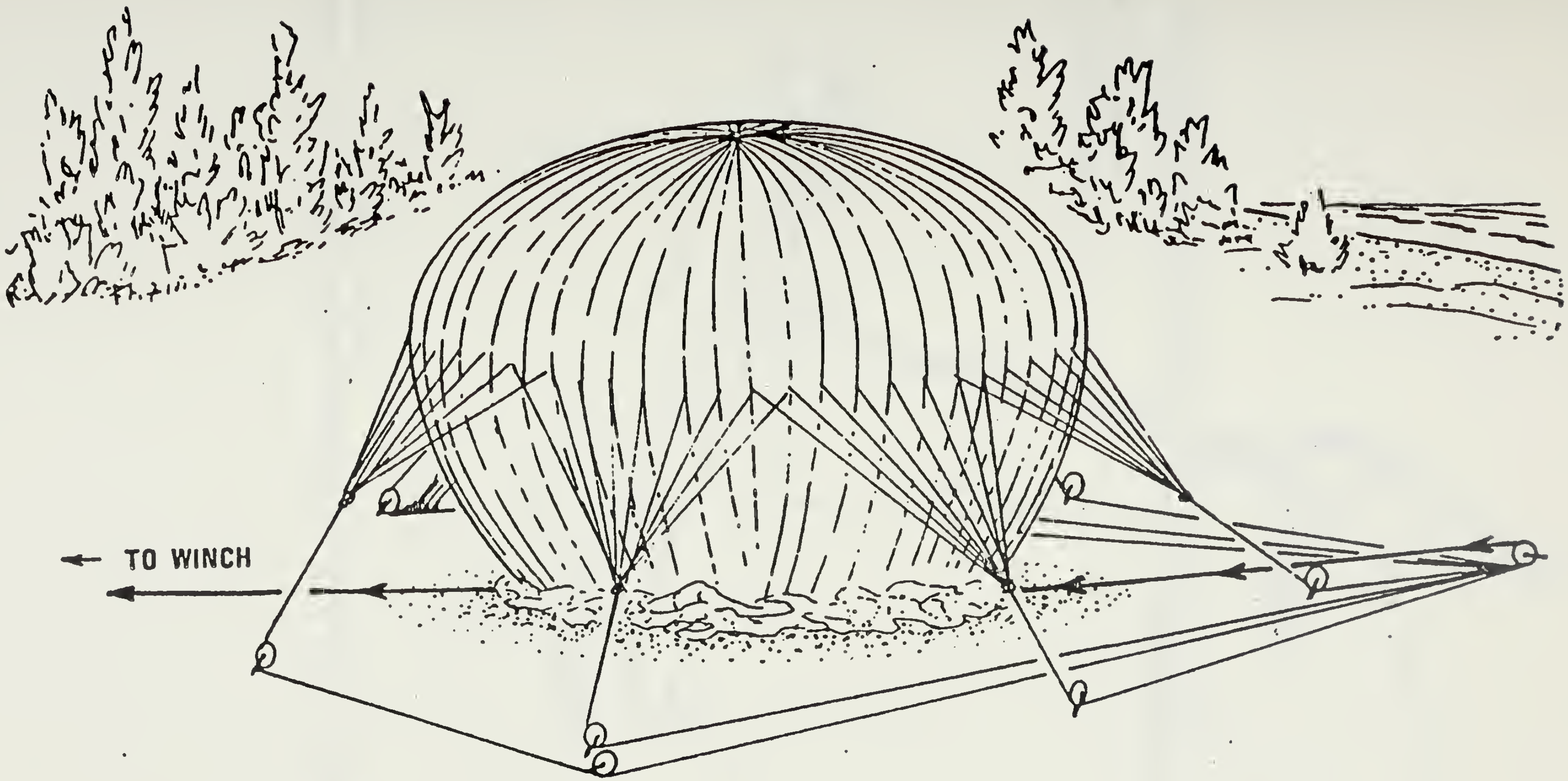


Figure 21. Moored Configuration.
Source: Air Force Range Measurements Laboratory, Balloon Feasibility Study.

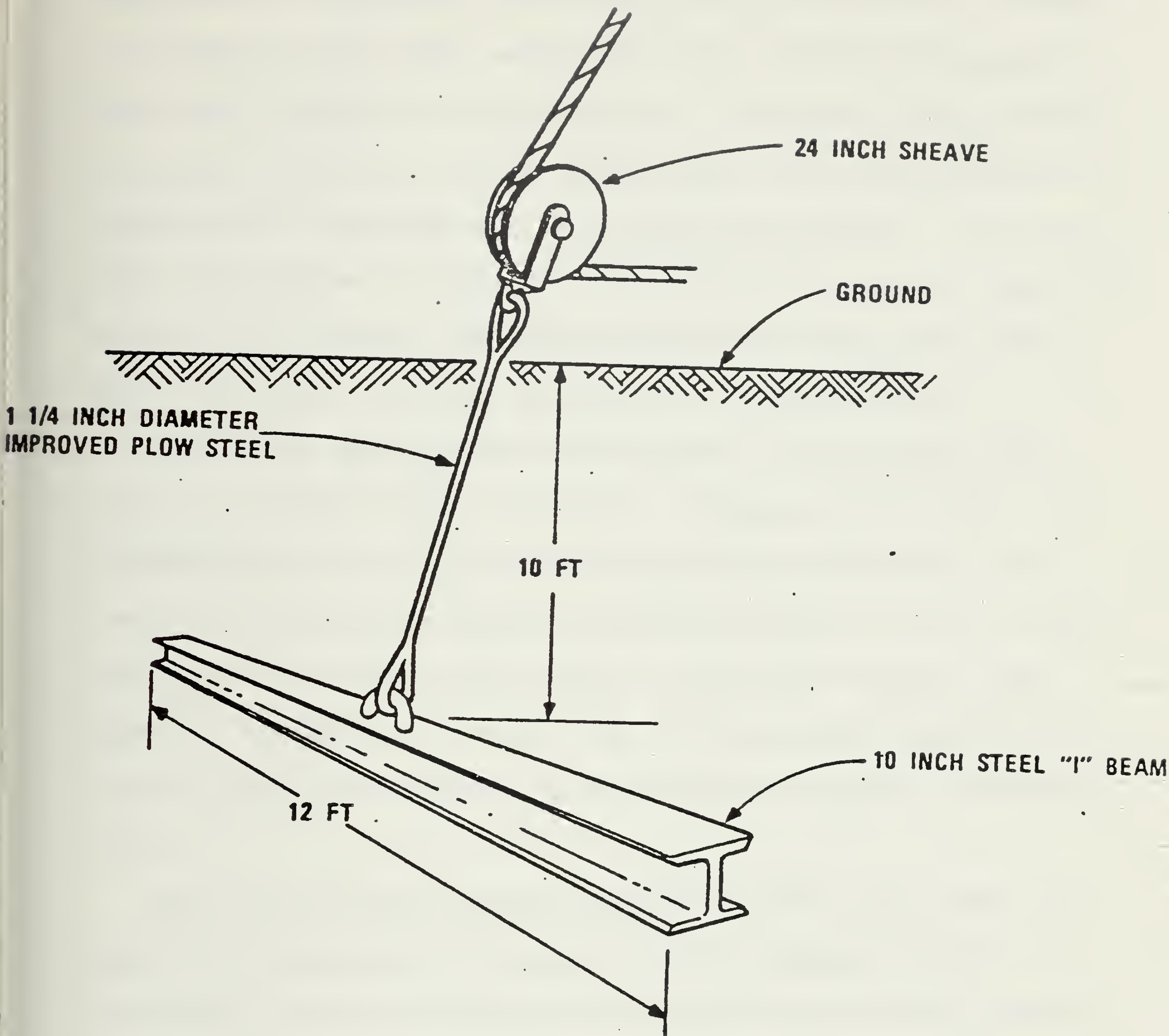


Figure 22. Anchor System.
Source: Air Force Range Measurement Laboratory, Balloon Feasibility Study.

inflated in a tethered state 200 to 300 feet above a transfer vehicle which must weigh more than the 30,000-pound upward force exerted by the balloon. Depending upon the road or ground conditions to be transited, both rubber-tired and crawler-type vehicles are used for this purpose. To illustrate the degree of mobility involved even with the inflated balloon, the entire system and equipment have been moved over distances of up to 80 miles in a single night.

Two-shift operations are routinely accomplished with the use of illumination devices. During recent years over 150,000 hours of full inflation operating time have been recorded on natural-shaped logging balloons. The only mishaps which occurred were cases in which the balloon was flown in conditions outside the routine rated flight conditions or due to malfunction in the ground support equipment (52).

To date balloon logging operations have only been conducted in mountainous terrain, and the optimum layout for the system involves transporting logs from felling sites above to loading or assembly sites below. Maximum efficiency is thus gained when the logs are moved downhill and gravitational force augments the winch pull producing faster movement with less strain on the yarder winch assemblies. In this configuration fuel consumption and machinery wear are minimized. Although maximum efficiency is gained by moving payloads downhill, the system also operates well in moving payloads horizontally or uphill, and the system is profitably efficient in any mode or layout.

B. BALLOON DESIGN

1. Shape

The greatest aerostatic lift efficiency occurs in balloons shaped like spheres, and the natural-shaped balloons now found in balloon transport systems approximate such a shape. This shape (as well as the inverted teardrop, Figure 23) has minimum surface area per given volume and, therefore, minimum fabric weight. The payload force is transmitted primarily into the balloon meridionally, resulting in minimal circumferential stress.

After nine years of experience with the balloon design, the Raven Industries (producer of the natural-shaped working balloons) has determined that a natural shape is variable within definite bounds. Shape factor varies between the values of 0.0 and 0.4 and is used to describe the relationship between the inflated height and the diameter. A higher factor results in a flatter shape; i.e., the diameter is larger than the height. For practical purposes, at a factor of 0.0 the balloon weight is small compared to balloon weight. Heavy lift natural-shaped balloons are therefore designed at low shape factors where the balloon weight is much smaller than the payload (52).

2. Load Distribution

An important aspect of the natural-shaped balloon is the ability of the balloon to distribute the payload evenly into the envelope. This capability is of primary importance to transport operations because as the payload is released, the balloon and the system must absorb an in-

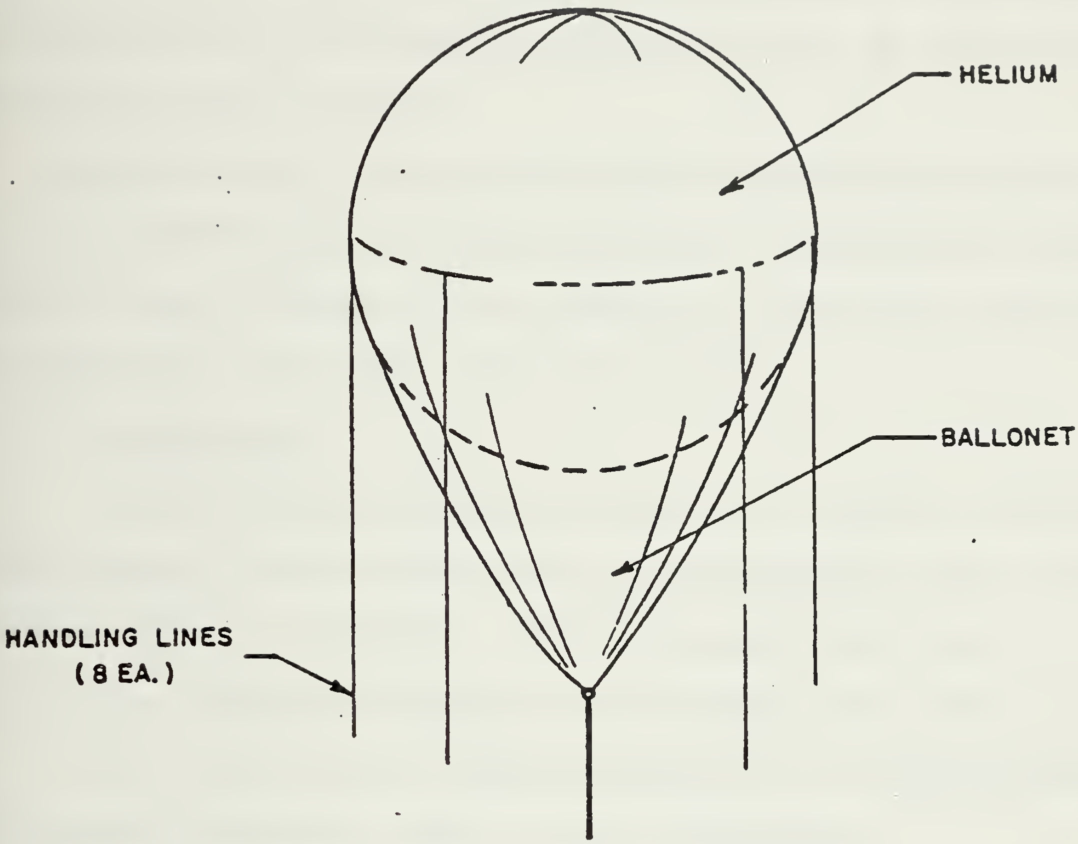


Figure 23. The Natural-Shaped Balloon.
Source: Naval Facilities Engineering Command, Joint Army-Navy Balloon Transport System Test, Final Report.

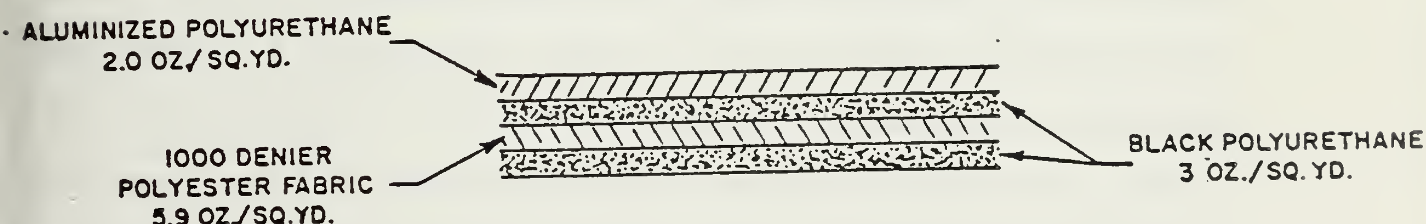


Figure 24. Material Construction Schematic.
Source: Naval Facilities Engineering Command, Joint Army-Navy Balloon Transport System Test, Final Report.

stant upward shock equal in weight to the payload. The uniform distribution allows the natural-shaped balloon to absorb shock loads with minimal introduction of the stress concentrations and bending moments as found in most aerodynamically-shaped balloons.

An additional advantage in the natural-shaped balloon is the capability of adding additional meridionally-directed, load-carrying members to the vertical gores thus amplifying the payloads which the design can carry.

3. Materials

The preferred balloon fabric is a layered polyurethane-coated dacron fabric with an aluminized outer surface coating (Figure 24) (53). Physical properties are:

a. Tensile strength of 400 pounds per inch.

b. Ultraviolet-light resistance at wavelengths and intensities normally found in the atmosphere.

c. A maximum permeability factor of approximately one liter per square meter per 24-hour period.

The coating is elastomeric and highly resistant to abrasion and wear. A continuous loop of steel cable is used as the top end fitting of the load webbing terminations, and steel cables also form the interface couplings between the load webbings and the bottom end fitting. Lightning protection is provided by a top-mounted tower and multiple braided cables extending down the load webbings to the bottom fittings. This fitting incorporates a multiple swivel and is coupled to the double tether lines.

4. Characteristics

Ten years of experimentation and design have produced a family of very reliable and rugged natural-shaped balloons; the characteristics of these balloons are summarized in Table 2 (54). A careful review of this data will reveal that the surface area of a natural-shaped, nonrigid balloon increases with the square of the diameter, whereas volume and lift increase with the cube. Sideward forces created by winds are therefore proportionately less on the larger balloons as illustrated by the leanover angle which decreases as size increases.

The balloons are normally inflated to 90% of full volume to allow for temperature and pressure altitude changes. At this level of inflation, the lower portion of the balloon is slack, and an ambient wind pressurization skirt is used to protect it. The skirt also serves as a load transfer coupling between the balloon and fittings.

5. Maintenance

Maintenance of the balloons is minimal. After the initial inflation, the balloon is first thoroughly checked for small holes which are repaired on site with cold patches. The lightning mast is then installed on top of the balloon. Since very little gas is lost through the polyurethane envelope, after initial inflation, only the addition of a few hundred pounds of helium every three to six months is required to keep the balloon operating normally.

Models	250 K*	530 K*	670 K	815 K	1000 K
Volume (ft^3) x 10^3	250	530	666	815	1000
Diameter (ft)	81	105	115	122	130
Height (ft)	87	113	113	131	140
Approximate Weight (lbs) x 10^3	3	6.2	3.2	8.8	9.6
Net Use Lift (lbs) x 10^3					
Sea Level	11	25	26.6	40	48
5000 Feet	9.5	20.7	3.1	33	42
Approximate Wind Drag (lbs) x 10^3 (at 25 mph)	2.4	4.1	3.1	5.5	6.3
Lift/Drag Ratio	4.6	6.1	10.3	7.2	7.6
Leanover Angle (at 25 mph)	12^o	9^o	9^o	8^o	7^o
Estimated Lift Loss (lbs/day)**	25	40	40	50	60

*Designed, tested, and available now.
**Loss due to gradual leakage of lifting gas.

Table 2. Characteristics of the Natural-Shaped Balloon.
Source: Advanced Research Projects Agency, An Evaluation of the Feasibility of Utilizing Balloon Systems for the Ship-to-Shore Transport of Military Cargo.

C. CURRENT TRENDS

1. General Limitations

As technical problems such as chronic mechanical problems in the yarder winches were eliminated and experience was gained, the balloon transport system gradually developed into a rugged, reliable system for yarding logs from inaccessible areas. This progress has been limited, however, by several parameters of great concern to the industry. These parameters provide physical limitations to the adaptability of the technology, and they include distance capability, cycle time, high coefficient of drag in the natural-shaped balloons, and system sensitivity to snow and wind conditions. The balloon transport system as presently configured cannot be improved without confronting one or more of the above limitations. Current efforts at system development and improvement involve mitigating or, when possible, eliminating one or more of these problems.

2. Specific Limitations

a. Distance

One limitation to the system is the distance over which payloads can be transported. This distance is presently limited by the lengths of the cables that can be safely controlled by the haulback winch drums of the yarders. It is now limited to a maximum of 3600 feet with a normal operating distance of 2500 to 2600 feet. Future systems now under development will increase this distance up to a mile or more.

The distance problem also has a more subtle dimension. The wire rope which controls the cables weighs approximately

two pounds per foot. If the weight increases in direct proportion to the length of the cable, it results in a decrease of payload unless the balloon size itself is increased. Increasing the size increases the drag forces which in turn require heavier cables and more powerful winches. Therefore, a delicate balance between several complex, interrelated aspects is required (see Table 3).

b. Cycle Time

Cycle time (the time required to pick up a load, transport it to the discharge site, and return) is directly controlled by three independent factors: the distance travelled, the hook-up time, and the speed of the winch drums on the yarder winches which move the balloon and its payload back and forth. The cycle time has enormous economic impacts on the balloon transport systems in the commercial world because multiples of the cycle times per given time period determines the amount of material which can be moved. This factor is therefore the central pivot point on which the system's efficiency depends. The system must not only be physically capable of moving loads from place to place, but it must also be capable of doing it efficiently and profitably. For these reasons significant efforts in research and development have been made to increase the speed and reliability of the yarder winches. These efforts have resulted in newer, improved yarder winches capable of operating at speeds in excess of 2400 feet per second, and even further improvements are possible.

		V_R		Balloon Volume (Cubic Feet)			
	C_D	V_b	V_w	700,000	1,250,000	1,500,000	2,000,000
NATURAL SHAPE	0.2	30	0	284	418	472	572
		30	30	1,137	1,674	1,891	2,291
	0.5	30	0	710	1,045	1,180	1,430
		30	30	2,840	4,180	4,720	5,720
	1.0	30	0	1,420	2,090	2,360	2,860
		30	30	5,680	8,360	9,440	11,440
AERO-DYNAMIC SHAPE	0.15	30	0	213	314	354	429
		30	30	853	1,256	1,418	1,718

Table 3. Winch Horsepower Data.
Source: Air Force Range Measurements Laboratory, Balloon Feasibility Study.

c. Design

The balloons themselves are also being continually improved. Based on more than ten years of operational experience with the current logging balloons and on wind tunnel tests on models, the design of newer balloons has been modified to extend the limits of the system. New envelope materials with better physical characteristics and more strength are now being used in the construction of the balloons.

The problem of high coefficient of drag in the natural-shaped balloon is a result of the resistance developed by the balloon as it moves through the air. This problem is aggravated if the balloon is moving against the wind and can only be reduced at a given envelope volume by either aerodynamically shaping the balloon or installing an internal ballonet. Although the aerodynamically-shaped balloon was abandoned in favor of the natural-shaped balloon for heavy lift purposes, this determination might have been made with relatively primitive trial and error techniques applied to existing balloons designed for other uses. Very little analytical investigation of the associated facts entered the decision-making process. Because the natural-shaped balloon was simple and rugged, it was adopted and refined for use in the balloon transport system in spite of the disadvantages of high coefficient of drag and wind sensitivity.

The natural shape of the balloon itself has been modified to introduce a rounded top (versus the older, flatter top which accumulated snow and presented an operational haz-

ard) and a ballonet installed in the interior of the balloon (52). The ballonet inside the balloon is a recent development which incorporates an interior compartment of variable volume which eliminates the slack bottom portion of the balloon at 90% inflation and provides increased stability. As a result, the balloon skirt is being shortened.

An adaptation of the balloon transport system developed in the logging industry can be found in the port of Hodeida, Yemen Arab Republic where a tethered balloon transport system has achieved limited success in reducing port congestion. The first balloon in the system, the Queen of Sheba, had a lift of ten tons and went into operation on September 26, 1977 (55). It featured a 530,000 cubic-foot natural-shaped balloon obtained from the logging industry. This balloon travelled back and forth between the vessels moored offshore and the shoreside docks. A mobile, multi-drum winching system, two anchor buoys, and normal offloading supplies are the only necessary pieces of equipment other than the balloon and its cables (55). The Queen of Sheba travelled at speeds of 1000 feet per minute, handled 800 tons of general cargo per day, and was credited with reducing port congestion by 35% in three months of operation before an accident during unusually high winds caused extensive damage to the envelope resulting in halted operations. Undaunted by this temporary setback, Yemen Skyhook Company, owner of the balloon transport system in Hodeida, now has plans to replace the older balloon previously used with a

newer balloon containing an internal passive ballonet, which should decrease the wind sensitivity and improve the system.

D. POTENTIAL IMPLICATIONS

1. Economic Factors

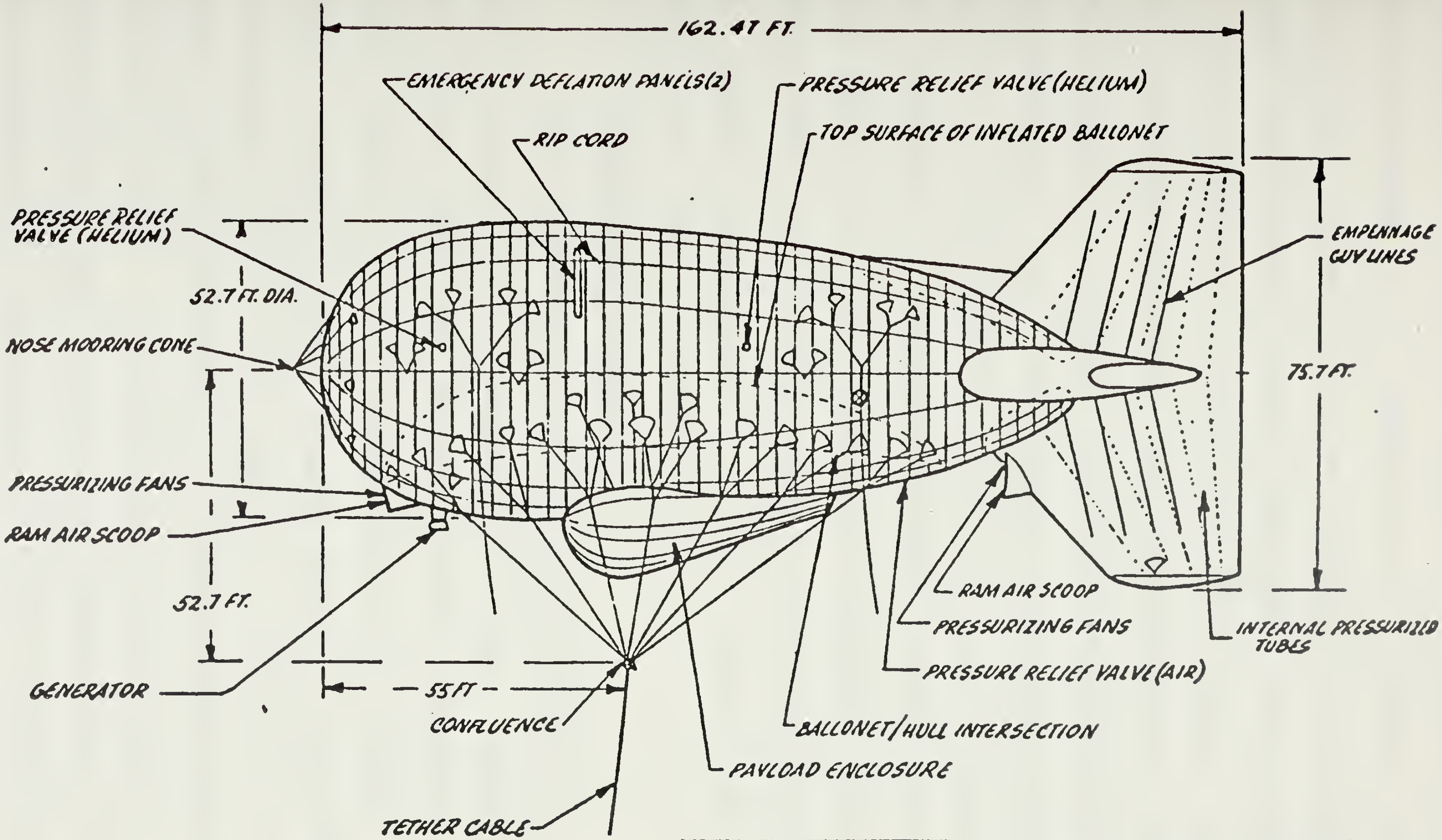
The future of the balloon transport system is already secure due to its profitability. Recent recognition of timber as a replenishable but dwindling natural resource, however, has created a positive economic force which will have profound effects on the future use of the system. A continual increase in the value of timber and the rapid development of technologies aimed at utilizing the entire tree have made it necessary to recover every possible fiber of wood. It is rapidly becoming apparent that sending high-priced cutters and fellers into the mountain forests to shatter five to ten per cent of the total timber volume in the felling processes involved in working steep hillsides and canyons is not a sound practice. It is also detrimental to continue skidding and dragging the timber to staging areas by conventional logging techniques resulting in a further loss of five to ten per cent of the remaining wood fiber. To overcome the losses due to conventional logging practices and to avoid expensive road construction costs, balloon yarding of logs is developing into an economic necessity which has minimal environmental damage as a by-product. This combination of forces will encourage the further development of the balloon transport system with the objective of lifting the entire tree package off the stump and out of the woods

to assembly areas where the entire tree can be worked for maximum utilization. To meet these challenges the system will have to dramatically extend the distance over which it can operate and become less sensitive to wind. As these conditions of increased distance and decreased wind sensitivity are met, the balloon transport system may find increased applications in other areas of the commercial world.

2. Design and Development

Recognizing that the techniques applied to previous balloon design and development had been largely trial and error with very little analytical investigation into the phenomena associated with tethered balloon flight, in the late 1960's the Range Measurements Laboratory began an extensive research and development program with the goal of developing a stable tethered platform for exploiting balloon-borne sensor applications. The result of this research effort was the development of the Family II Balloon (Figure 25).

These balloons are unique in that they are aerodynamically-shaped, but without many of the problems of previous designs. The initial Family II Balloon is described as an aerodynamically-shaped, single-envelope, ballonet balloon with a cruciform stabilizer (cross-shaped tail assembly). It is constructed of urethane Dacron laminate material and is designed to survive 90-knot winds at sea level. The ballonet, located within the envelope, is pressurized by blowers which obtain air through chin scoops located on the lower portion of the hull. The cruciform stabilizer is located



VOLUME	201,000 CU.FT.	5,692 CU.METERS
DESIGN ALTITUDE	10,000 FT.	3,048 METERS
GROSS PAYLOAD W/PWR SUP.	1,600 LBS.	726 KILOGRAMS

Figure 25. The Family II Aerodynamically-Shaped Balloon.
Source: AirForce Range Measurements Laboratory, Balloon Feasibility Study.

much further aft on the hull than on conventional aerodynamic balloons and is pressurized by blowers for structural stiffness. Guy-wire bracing between the vertical and horizontal stabilizers provide additional structural stiffness.

The cruciform configuration was selected for this design because it provides the same aerodynamic stability with more structural rigidity than the Y-configurations of equal platform area (56). Aerodynamic shape and structural integrity are maintained by an automatic pressurization system that operates electrically-powered blowers and relief valves that control hull and empennages pressure. An on-board motor generator provides electricity for these controls. The physical dimensions of various sizes of the Family II balloon are shown in Table 4.

3. Commercial Adaptation

The commercial world has been quick to recognize the vast potential of the Family II design. Commercial adaptation of the basic 200,000 cubic-foot design has produced both a 250,000 and a 350,000 cubic-foot design. The advantages of adapting this balloon shape to the balloon transport system are readily apparent. Compared to the natural-shaped balloon, the Family II balloon has very little coefficient of drag. This decreased coefficient of drag imposes substantially lower horsepower requirements on the winch system making vastly increased distances technologically more approachable. In addition, the demonstrated ability of the balloon to survive and perform under high wind conditions introduces an all-weather possibility previously missing in

	#1	#2	#3
Balloon Volume (ft^3)	1,250,000	1,500,000	2,000,000
Gross Lift at 100% Inflation (lbs)	82,375	98,850	131,800
Net Lift (lbs)	53,000	66,000	90,000
Balloon Diameter (ft)	95	102	112
Balloon Length (ft)	253	269	296
Empennages Height (ft)	137	146	160

Table 4. Characteristics of the Aerodynamically-Shaped Family II Balloons.
Source: Air Force Range Measurements Laboratory, <u>Balloon Feasibility Study</u>.

the system.

These advantages, however, will not be obtained without increased balloon costs. The aerodynamically-shaped balloon is much more complex than the natural-shaped balloon and, as a result, is 2-3 times more expensive. Maintenance costs are also increased. The reduced coefficient of drag, then, is possible with an accompanying increase in the complexity of the balloon envelope.

V. THE DEVELOPMENT OF THE MILITARY BALLOON TRANSPORT SYSTEM

A. OPERATIONAL REQUIREMENTS

Conceptually, the logistics over-the-shore container discharge operation is very similar to the transportation of logs from one place to another; however, the details of the military system and potential operating environment differ significantly. Before evaluating the feasibility of applying a balloon transport system to the logistics over-the-shore problem, it was first necessary to define the operational requirements for the proposed system.

To determine the degree of potential user interest in the balloon transport system, the Defense Advanced Research Projects Agency (ARPA) hosted a conference of personnel from the military services. At this 1972 conference, Raven Industries, Inc. of Sioux Falls, South Dakota, a balloon manufacturer, conducted a briefing on the characteristics and the performance of logging balloon systems. The application of a system using similar components for the off-shore discharge of containerships was discussed, and the implementation of a program for examining the feasibility of using a balloon system to meet the military requirement was proposed.

At the same time, ARPA indicated that it would provide funding support for feasibility evaluation and demonstration if the military transportation community could establish that a need existed for the system. Specifically, ARPA re-

quested service input concerning the following points (54):

1. Is there a definite requirement for a transport system for ship-to-shore military cargo transport, could a balloon transport system contribute to such a system, and does the system presented at the meeting merit evaluation for transportation purposes?

2. What problems are envisioned in a balloon transport system for ship-to-shore cargo transport?

3. What comments or suggestions are offered for a balloon transport system feasibility evaluation program?

In response to this request for information, letters were received from the following commands: U.S. Army Deputy Chief of Staff, Logistics; U.S. Army Material Command; U.S. Army Mobility Equipment Command; U.S. Army Combat Development Command Transportation Agency; U.S. Naval Facilities Engineering Command; and U.S. Marine Corps Deputy Assistant Chief of Staff (54). These letters verified the need for the proposed system, demonstrated significant interest, and urged that evaluation of such a system be undertaken.

Subsequent conferences developed service requirements, raised questions, and discussed potential problem areas regarding the design, operation, and cost of a balloon transport system. When the results of these conferences were tabulated, it was possible to develop operational requirements peculiar to a military balloon transport system. Specific requirements for a transport system for ship-to-shore discharge of military cargo are:

1. Extraction of loaded containers weighing 22.5 tons

and measuring 8x8x20 feet from cells up to six containers deep and the discharge of them from the containership at a rate of at least 12 per hour.

2. Carriage of the containers to shore positions up to five miles away from the ship.

3. Operation in steady winds up to 10 knots, with gusts to 20 knots, and in sea state one conditions (the capability to operate in sustained winds of 15 knots, with gusts up to 25 knots, and sea state two or more would be desireable).

4. Tolerance of high and low temperatures and operation in all but the most extreme environmental conditions.

5. Operation over all surf and terrain conditions at the beach and inland.

With the objective of establishing the feasibility of the application of the balloon transport system to military situations, ARPA approved funding for two tests to be conducted by Range Measurements Laboratory (RML), Patrick Air Force Base. In late 1972 and early 1973 the first two Oregon field tests (57, 58) were conducted. Following these tests the Navy Facilities Engineering Command (NAVFAC) funded two tests aimed at providing critical technical information essential to system scale up estimates. These tests were: the third Oregon field tests (59) with the objective of determining the exact coefficient of drag to be expected with the natural-shaped balloons, and a study of the vulnerability of tethered balloon systems (50).

In the fall of 1973 the Army was designated as the lead service for tethered balloon development. After the Oregon

tests and NAVFAC's vulnerability study, NAVFAC and the Army jointly funded a concerted engineering study performed by RML in 1975 (28) and an additional test to obtain hard test data and demonstrate the system potential (53). Independent of the Army/NAVFAC efforts, RML conducted the Stapleton Logistics Experiment to determine if their aerodynamically-shaped balloon would adequately perform as a tethered balloon (60).

B. FIELD TESTS

1. General

As previously mentioned, tethered balloon activities have been conducted since the late 1960's by RML. This work began when ARPA tasked RML to develop a stable balloon platform for the exploitation of balloon sensor applications. Realizing that the rechniques applied to previous balloon design and development had been largely composed of trial and error methods, RML applied advanced analytical investigation to the phenomena associated with tethered balloon flight. Eventually (1971) they developed the first of the Family II balloons, an aerodynamically-shaped ballonet balloon with a cruciform stabilizer. It represented a major advance in balloon technology; and, therefore, RML appeared a natural choice to evaluate the feasibility of adapting the heavy lift, natural-shaped balloon used by the logging industry for harvesting timber to the logistics over-the-shore problem of discharging containerships across undeveloped beaches.

2. <u>Test Series I: October, 1972</u>

a. Objectives

The Range Measurements Laboratory conducted the first of its tests during October, 1972 in Culp Creek, Oregon. This test was designed primarily to obtain a feel for associated problems and to demonstrate initial feasibility. Specific objectives were:

1. Determine the feasibility of handling cargo containers with a balloon system.

2. Obtain documentary photographic evidence of the transport of 20- and 40-foot containers.

3. Obtain preliminary data as to cycle time, rigging problems, sling/container interface, etc.

4. Familiarize the crew in handling cargo containers for future demonstrations (57).

This test utilized an existing balloon logging system and its crew under contract to Raven Industries and Bohemia Lumber Company, the owner of the balloon.

b. Test Operations

The test operations were conducted at an existing logging site. Rigging and site layout are shown in Figure 26. Nine runs of 1500 feet back and forth were conducted in an alternating pattern: the 40-foot container was lifted from the lower site to the upper site, landed, and unhooked. The balloon was returned, and the operation was repeated with the 20-foot container. The 40-foot container was then returned to the lower site, followed by the 20-foot container. Average cycle time for the test runs was

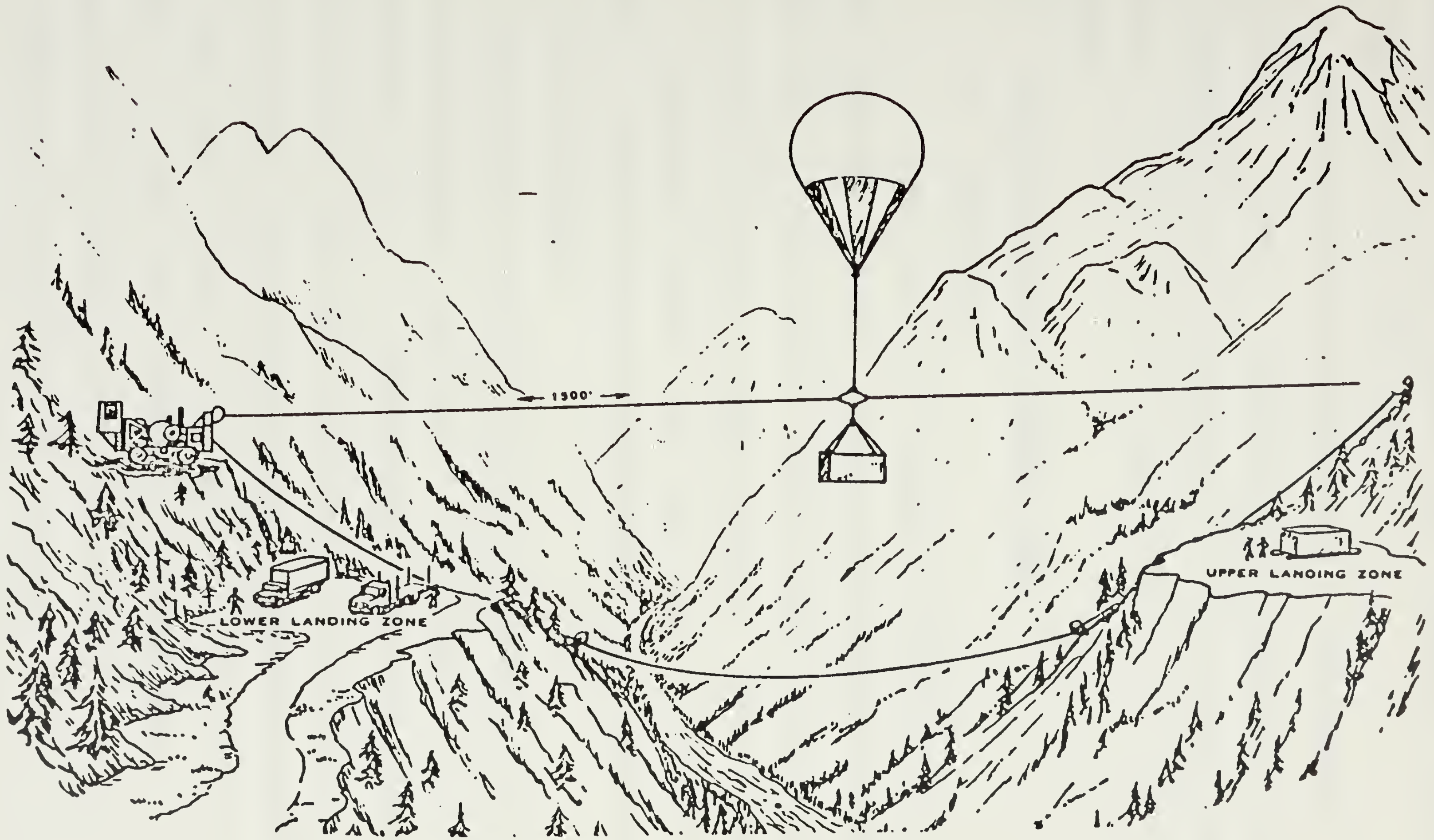


Figure 26. Test Series I.
Source: Air Force Range Measurements Laboratory, Balloon Feasibility Study.

three minutes, thirty-seven seconds. Complete photographic documentation of the evolution was obtained, and rigging problems were documented (57).

No problems were encountered in accomplishing all test objectives. Based on the successful results of these tests in demonstrating the feasibility of the balloon transport system, a second and more comprehensive test series was planned.

3. Test Series II: March, 1973

a. Objectives

The second test series evaluating the potential of the balloon transport system was conducted by RML in March, 1973 at Culp Creek, Oregon under arrangements similar to those outlined in Test Series I. The balloon in use had a volume of 530,000 cubic feet with a net lift of 24,000 pounds. Standard 20-foot MILVAN containers were used throughout the test series.

The general objective of the test series was to obtain data pertaining to the dynamic conditions and performance characteristics of a simulated balloon ship-to-shore transport system. Tests were conducted by simulating as closely as possible a ship-to-shore cargo transport scenario (61).

The first portion of the Series II field tests was intended to examine the operational performance of the balloon transport system in primary transport scenarios with the addition of the following follow-on tests (61):

1. Scenario S-1: using a spreader bar attachment device, extract a container from a container cell, transport

it a distance of at least 1500 feet, and deposit it in a general area with an accuracy of ±10 feet (simulated transport from ship to shore with broad placement latitude on the beach).

2. Scenario S-2: extract a container as in Scenario S-1, transport it a distance of at least 1500 feet, and deposit it with a relative accuracy of ±1.5 feet (simulated transport from ship to shore with specific placement).

3. Scenario S-3: extract a container as in Scenarios S-1 and S-2, transport it a distance of approximately 200 feet, and deposit it with relative accuracy of ±one foot (simulated transport to lighterage with visual control during final placement).

b. System Configuration

The configuration of the Test Series II operation is shown in Figures 27 and 28. A careful review of these diagrams will disclose that the balloon transport system envisioned for military application differs from the one used in the logging industry. This difference is found in the addition of the flying Dutchman line and winch assembly, incorporated to add a lateral control feature. The aerial end of this line attaches to a moving block (the flying Dutchman block) which rides freely on the main line. The flying Dutchman winch and line are so positioned that reeling in or out on the winch deflects the balloon laterally with respect to the linear path between the off-shore winch and the onshore discharge point. This feature allows access to all cells on the containership. The configuration shown

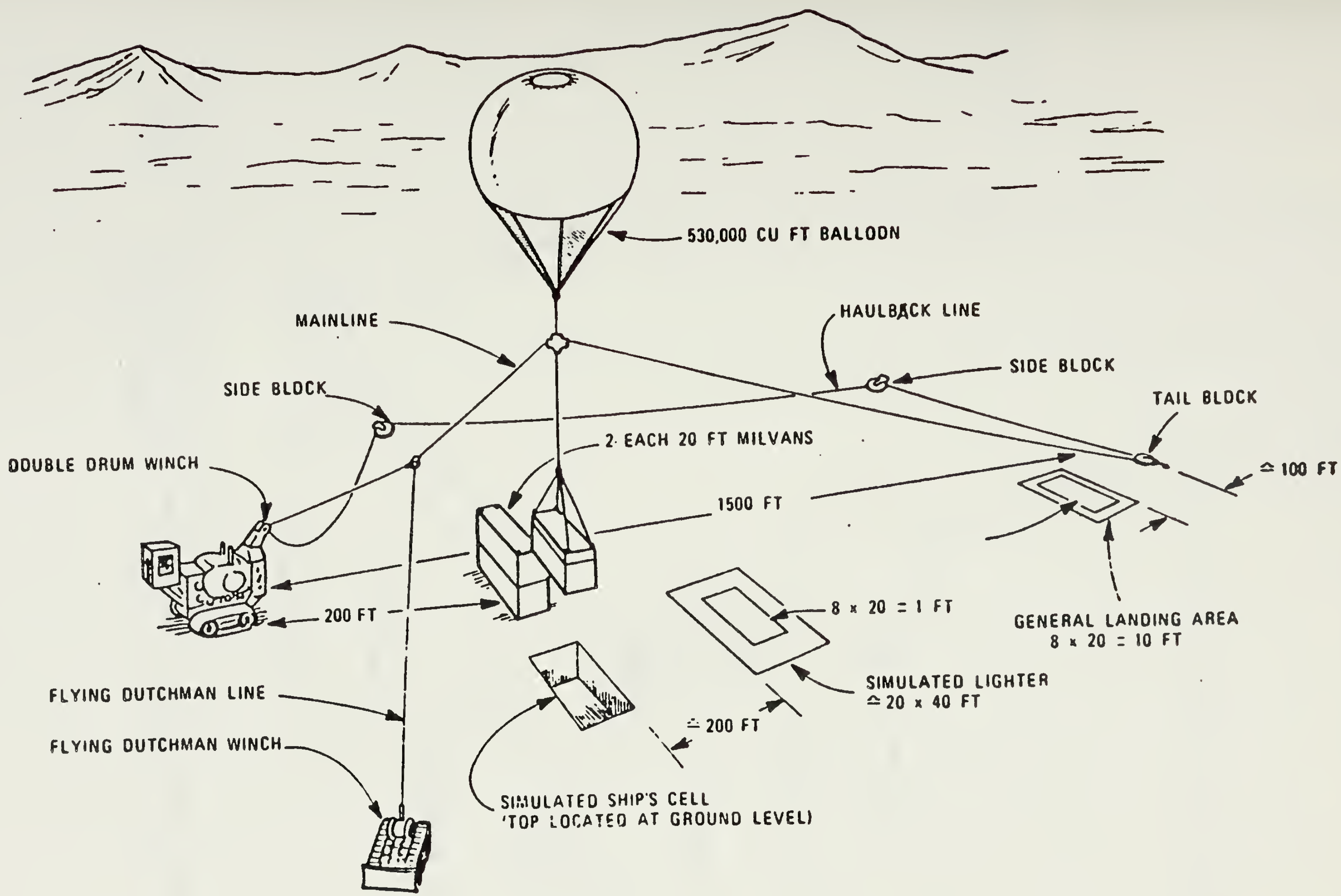


Figure 27. Test Series II (Site Layout).
Source: Air Force Range Measurements Laboratory, Balloon Feasibility Study.

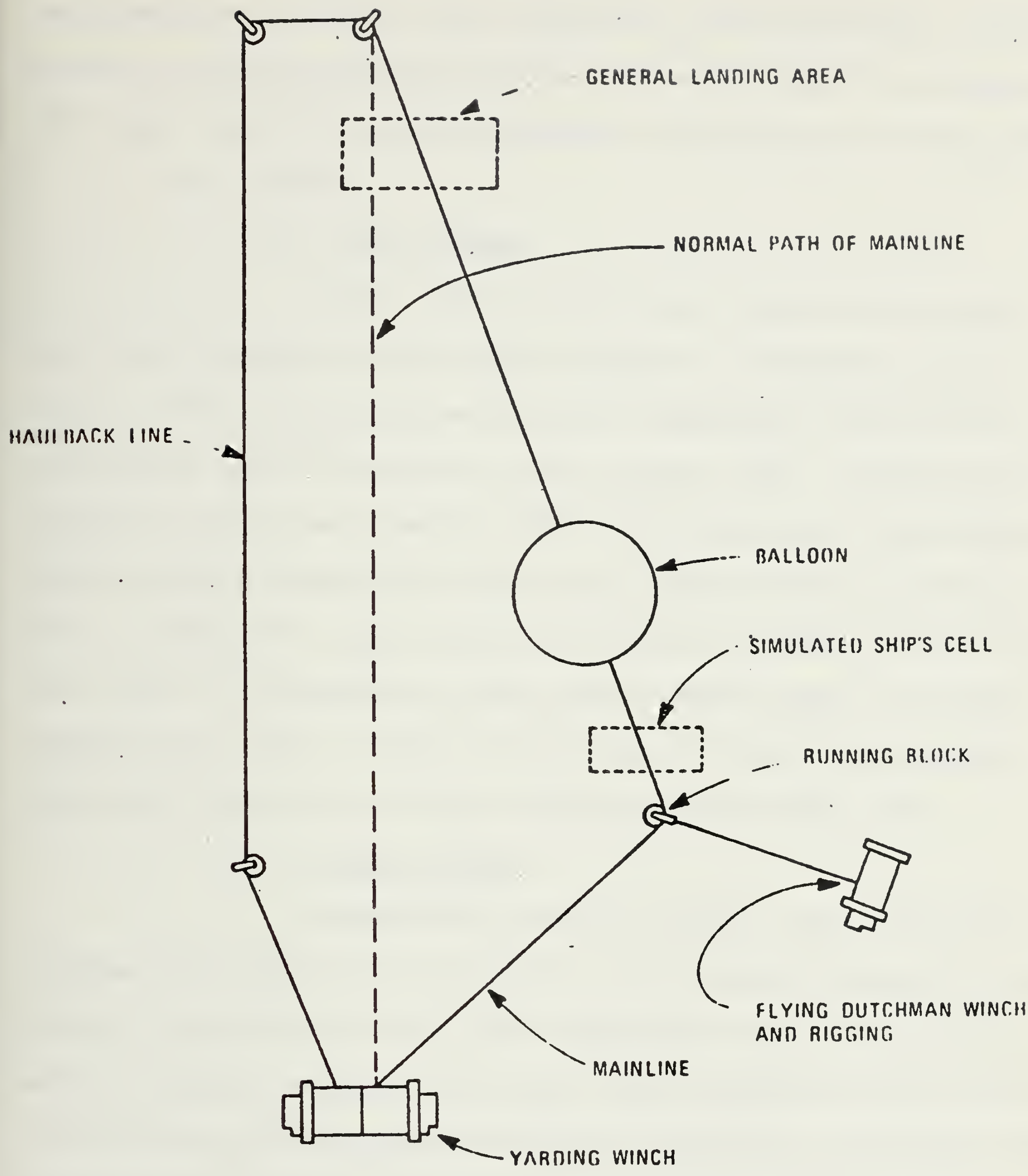


Figure 28. Test Series II (Plan View).
Source: Air Force Range Measurements Laboratory, Balloon Feasibility Study.

represents only one of many possible configurations; for example, a second flying Dutchman and winch could be placed on the other end to provide increased flexibility in the system.

c. Results

(1) <u>Cycle Times</u>

Each test scenario was repeated 22 times, and the accumulated data was averaged to determine cycle times. The average cycle time for scenarios 1 and 2 was calculated at six minutes, four seconds (58). With an increase in the line speed to 2000 feet per minute and acceleration and deceleration at 0.3 g, the time for operations over a 1500-foot range could be reduced to under three minutes (61). Extrapolating this improvement over a one-mile range would yield a total cycle time of about six minutes per cycle or a rate of nine containers per hour (28).

(2) <u>Cable Forces</u>

During the testing period, data was accumulated and analyzed to determine the forces carried by the cables. Analysis of this data indicates that the main line and the flying Dutchman line had their maximum tension when the balloon was positioned over the simulated container cell. During this interval, both the main line and the flying Dutchman line were subject to the maximum force of the system. After the container was extracted, the main line force decreased and the haulback line force increased while the balloon was pulled toward the landing area. In the landing zone, both main-line and haulback-line forces were intermittently increased and decreased during landing maneuvers.

At the time of container release, the force on the haulback line increased rapidly until the full upward force of the balloon was absorbed. During the accelerated run back toward the loading area, the main line took an accelerating force which peaked when the balloon was again centered over the container cell.

(3) Binding Problems

Close observation of container operations prior to Test II revealed that the shore-based gantry cranes commonly used to discharge containers are able to control six degrees of freedom (three degrees of translation and three degrees of rotation). This amount of control is not possible with the balloon transport system, and it becomes a matter of some concern due to possible container-cell framework binding. With the reduced amount of control available and the small clearances of the rattle space in the cell framework, situations could arise in which the container might bind or jam in the cell. Misalignment of the lifting cable or offset of the center of gravity of the load could generate torque actions which create natural gravitational forces and frictional forces capable of locking the container in place. The most common case would be the condition in which the container is cocked in the cell with an upper edge and the opposite lower edge pressing against the cell guideways of the framework. In several recorded instances where this jamming has occurred, even under the close control of the gantry crane, it has been necessary to cut the container free.

In an effort to better understand how binding problems could affect container extraction when the pitch and roll motion of a ship in a sea environment tends to tilt the cell relative to the vertical direction of the force of gravity, tests were conducted with simulated conditions of pitch and roll. Although tests in a dynamic situation with continually changing pitch and roll conditions would have been more desireable, the static test conducted did provide considerable insight into the problems of possible binding. Thirty extractions were made with various conditions of off-center container loading and with various cell-pitch angles and associated roll angles deliberately created by tilting the simulated container cell (58). Throughout this procedure, the extractions were accomplished without serious difficulty, although friction between the cell framework and the container increased with the degree of induced pitch and roll. It is predicted, however, that this friction can be reduced by lubrication of the cell framework guides before deploying from CONUS.

(4) Shock Forces

Balloons and cables used in the balloon transport systems of the logging industry are often subjected to sudden shocks created by load changes. Since similar conditions would also occur in the military balloon transport system, a series of dynamic tests with containers was conducted to determine possible effects (58).

In the first of these tests (release jerk), the balloon was pulled down as far as possible, released, allowed to

run free for a short time, then quickly stopped with the winch brakes. This test proved that at the instant the balloon is jerked to a stop, the upward momentum of the balloon applies an additional force above the buoyant force. This force was calculated to be 50% higher than the normal 23,000 pounds upward buoyant force naturally occurring in the system, and it is predicted to have some value in extracting containers when binding occurs in the cell guideways. Common sense indicates, however, that this method of resolving binding problems must be used cautiously to prevent further and/or complete jamming of the container in the cell.

In the second of the shock tests (load bounce), the balloon, carrying a heavy load, was pulled rapidly down until the load struck the ground. The balloon, several hundred feet above, continued downward due to momentum, then reversed direction and shot rapidly up until it was restrained by the connecting cables. At the instant in which the balloon's upward ascent was stopped, the shock distributed into the balloon envelope exceeded that normally occurring during flight. The balloon and associated cable assembly absorbed both these shock tests without damage.

(5) Rigging

Two separate rigging configurations were evaluated during the test series: the travelling skyhook with ground return of the haulback line (Figure 29) and an inverted skyline (Figure 30). While both configurations

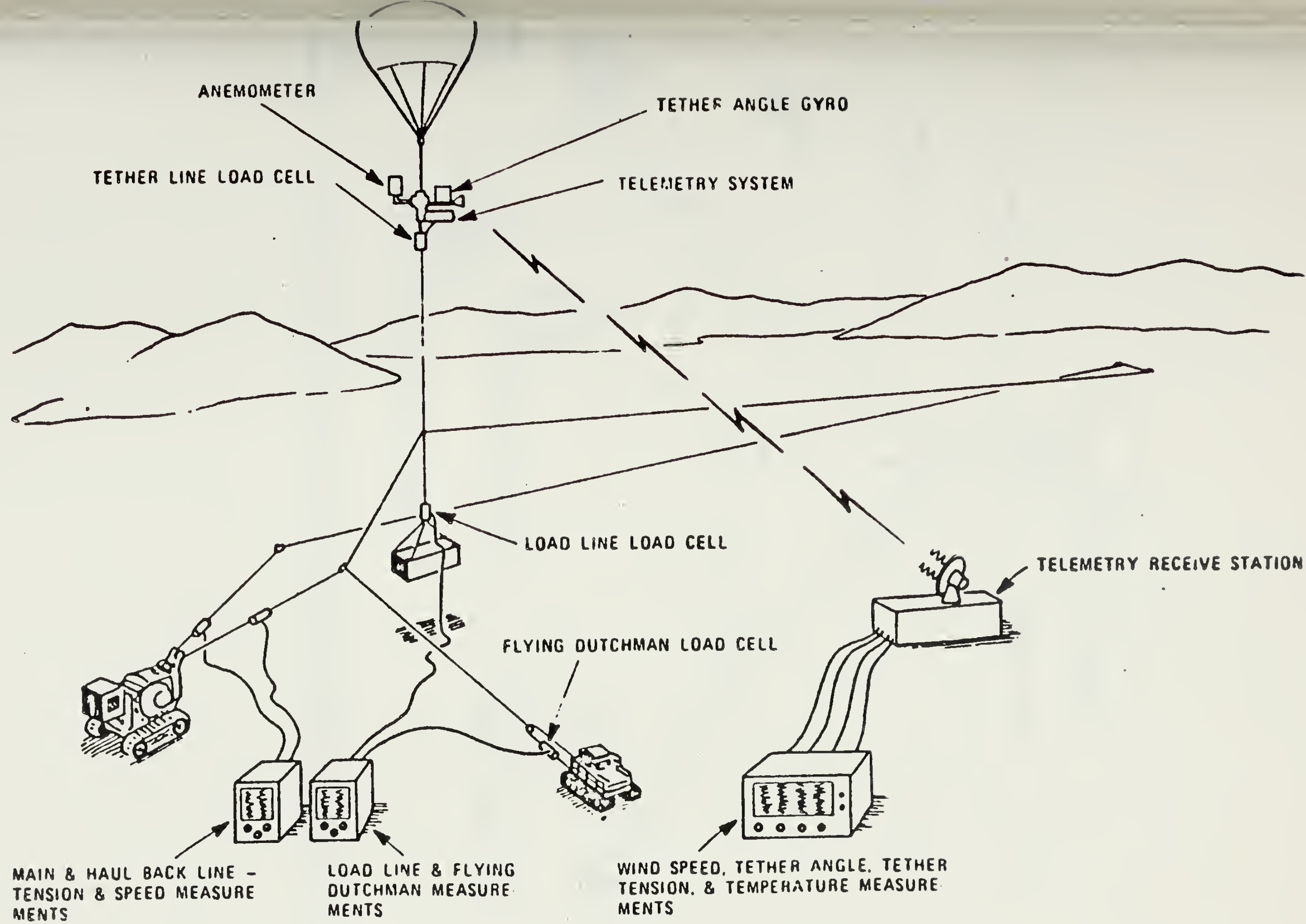


Figure 29. Travelling Sky Hook with Ground Return of Haulback Line.
Source: Air Force Range Measurements Laboratory, Balloon Feasibility Study.

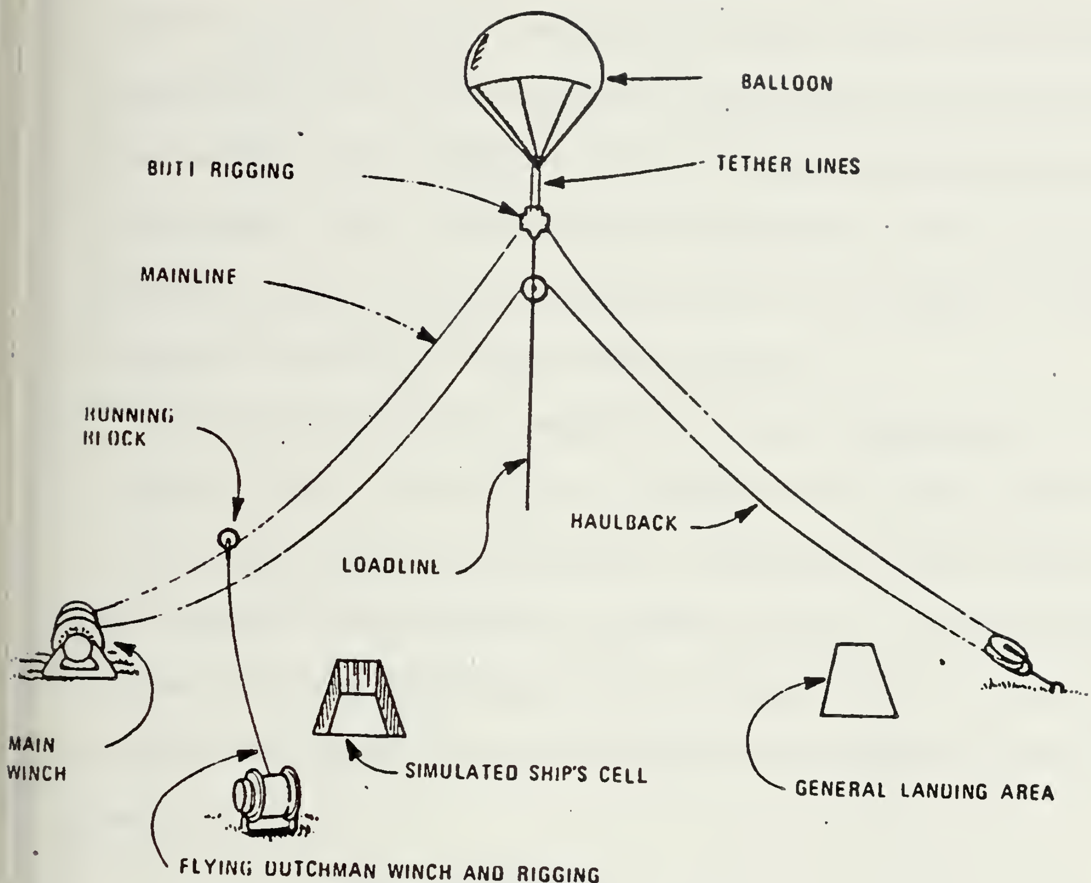


Figure 30. Inverted Skyline.
Source: Air Force Range Measurements Laboratory, <u>Balloon Feasibility Study</u>.

demonstrated adequate performance, the travelling skyhook system had the disadvantage of returning the line along the ground or, in the case of ship-to-shore operation, through the water. The presence of the return line in the water increased the amount of drag forces which the winch assemblies had to overcome, accelerated deterioration of the cable, and hampered ship- or lighterage-maneuvering in the area. With both lines supported by the balloon, these disadvantages can be eliminated at the cost of imposing a weight penalty in the system itself.

Optimum rigging conditions were developed in later tests using a winch assembly at either end of the horizontal run, thus completely eliminating returning cable problems in the projected ship-to-shore systems (28). The principle advantages of this rigging method (Figure 31) are less cable weight and drag to be overcome and reduced sheave wear of cable.

(6) Findings

The test results from the Oregon Test Series II were very positive, and they successfully demonstrated that the military application of the balloon transport system had significant potential. The envisioned system could extract containers from a simulated containership cell even with the center of gravity of the container offset more than 10% with cell pitch angles of five degrees and roll angles of 5.7 degrees, could transport these containers over a reasonable distance, and could deposit them with acceptable degrees of accuracy.

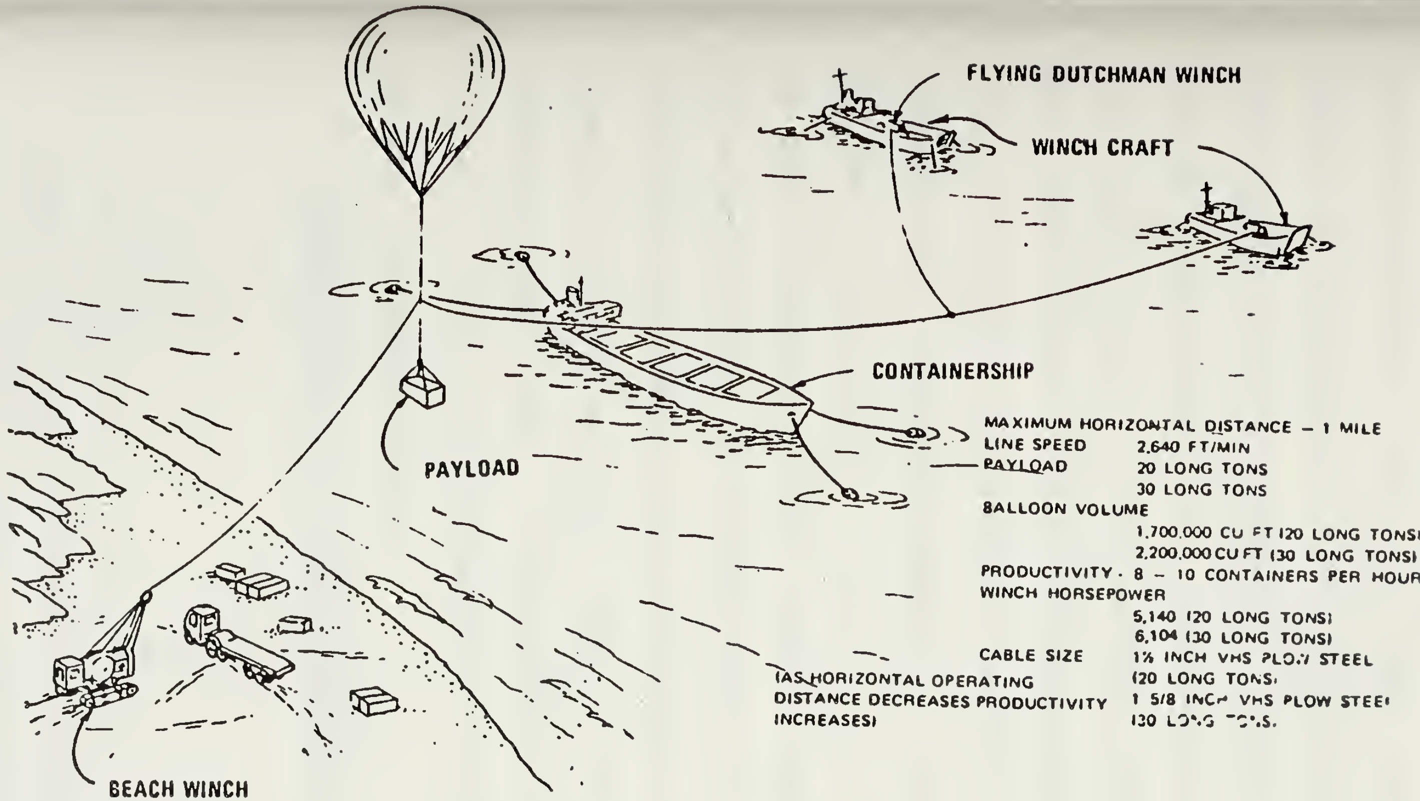


Figure 31. Ship-to-Shore System Concept.
Source: Air Force Range Measurements Laboratory, Balloon Feasibility Study.

4. Test Series III: November, 1973

During Test Series II, some aerodynamic tests concerning the coefficient of drag inherent in natural-shaped balloons had been conducted with inconclusive results. Accurate determination of the exact coefficient of drag to be expected with natural-shaped balloons was important because one of the most critical problems to be solved in the military application of the balloon transport system was the high coefficient of drag and its subsequent wind resistance. This resistance was created either by moving the balloon through the air (cable speed) or having air move past the balloon (wind speed), and for the balloon, these two forces were additive. With a ground speed of 20 miles per hour and a wind speed of 30 miles per hour, the relative velocity affecting the balloon was 50 miles per hour. A reduction of ground speed by one-half reduces the relative velocity to 40 miles per hour (59). The additive nature of these forces tends to create high horsepower requirements as illustrated in the following table:

Wind Speed	Cable Speed	Horsepower
0	10	50
0	20	400
10	20	900
20	20	1600

The test, also conducted in Oregon, utilized a 530,000 cubic-foot logging balloon tethered to a crawler tractor which was loaded on a flatbed transport vehicle and towed over a test track of 0.7 mile in length. This test covered

a range of relative wind velocities corresponding to wind speeds of five to thirty knots, and the results were similar to those produced in Test Series II. Tentative evidence indicated a drag coefficient 25% to 50% less than expected for higher velocities, as had been suggested by various early tests. These results also indicated that the system would benefit from the development of techniques to maintain balloon shape thereby preventing dimpeling effects. These effects lead to a further increase in the high coefficient of drag and a corresponding loss of efficiency. This objective provides direction for further useful research (59).

These early attempts to gain an understanding of the coefficient of drag for the natural-shaped balloon were not conclusive because the balloon was not fully inflated and, therefore, had a dimple in the forward surface. The uncertainty created by this dimple eventually became one of the principal reasons for later tests and demonstrations conducted in 1976 (62).

5. <u>Stapleton Logistics Experiment</u>

a. Objectives

This test was conducted on 1 May 1974 at Cape Canaveral, Florida by RML. The objective of the experiment was two-fold (60):

1. To evaluate the use of a Family II aerodynamically-shaped balloon system in a low altitude, heavy lift configuration.

2. To reconfigure the rigging of the balloon transport

system, eliminating the elaborate block assembly and ground-layed haulback line by placing a single drummed winch assembly at either end of the horizontal path of the balloon and connecting the two independently-controlled cables to the confluence point under the balloon.

A secondary objective was to gain experience in controlling the new configuration via voice communication on a radio link.

b. System Configuration and Operation

The principal components of the system were the balloon, two winch assemblies, and a tether cable used in the hookup. The balloon, Family IID-7, had a 200,000 cubic-foot volume and a gross lift capability of 13,800 pounds. It was 165 feet long and 52 feet in diameter, and it had a tailspan of 75 cubic feet. It had been manufactured to Air Force specification by ILC Industries of Dover, Delaware. The winches were manufactured by Otis Engineering Company of Dallas, Texas, specifically for use as tether winches for high-altitude tethered balloon systems. They held 20,000 feet of cable but operated at relatively slow speeds and were actually being used in a scenario beyond their design capabilities. They were independently controlled and were located approximately 1500 feet apart.

The buoyant lift of the balloon was used to extract a 5200-pound MILVAN from a concrete bunker (simulating a container cell), transport the MILVAN across a 1500-foot distance, land it on a flatbed trailer, and return it to the simulated container cell. The layout is shown in Figure 32.

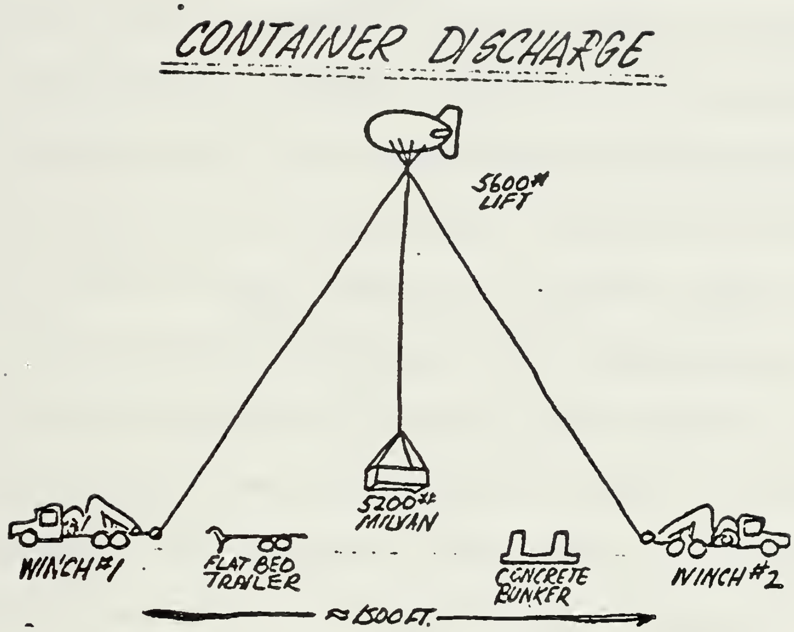


Figure 32. Stapleton Logistics Experiment Test Configuration.
Source: Air Force Range Measurements Laboratory, Stapleton Logistics Experiment.

Coordination of the system was provided by a voice radio link.

c. Results

This experiment demonstrated the practical feasibility of using the independently-controlled winches instead of one winch assembly with two drums requiring a block assembly arrangement for the control of the haulback line. It also demonstrated that an aerodynamically-shaped balloon can be operated in a low altitude, heavy lift configuration. The balloon lift of the Family II balloon used was marginal, however, and to meet the heavy lift requirement of the logistics over-the-shore application, it requires extrapolation of the present balloon design to give a helium volume of approximately 1.3 million cubic feet. An idea of the size balloon necessary is displayed in Figure 33.

During lifting operations control of the balloon was easily accomplished using the voice radio link. The only problem encountered was the speed limitation of the balloon winches which were specifically designed for high altitude tethered balloon operations where high winch speeds are precluded. This limitation increased cycle time considerably over that which would have been attained with the high speed yarders used in the logging industry.

6. <u>Joint Army-Navy Balloon Transport System Test</u>

a. General

Following the completion of the Oregon test series and the NAVFAC vulnerability study, the next step was to complete a concentrated engineering study and obtain further

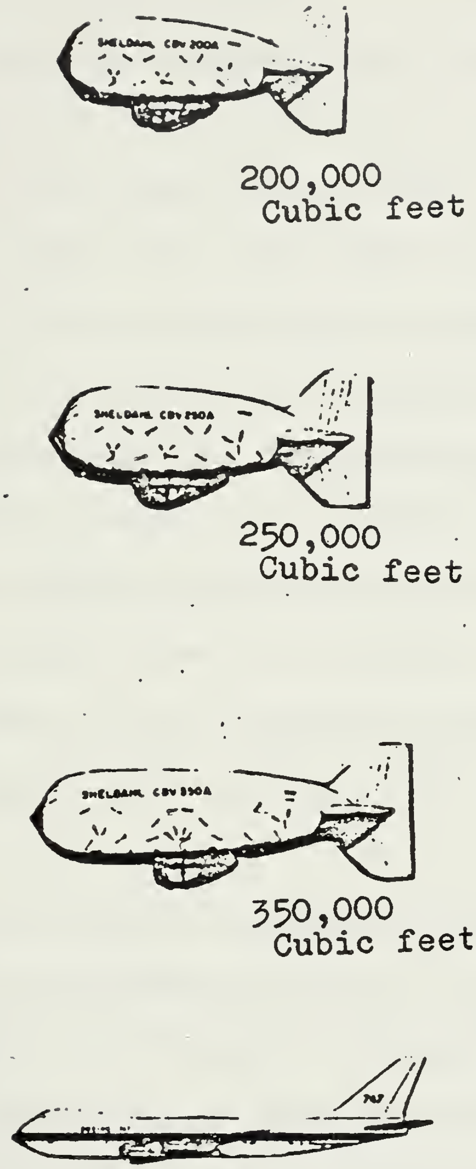


Figure 33. Comparison of Projected Family II Balloons and Modern Aircraft.
Source: Massachusetts Institute of Technology, Interagency Workshop on Lighter-than-Air Vehicles, Technology Update -- Tethered Aerostat Structural Design and Material Developments.

data on coefficient of drag for the natural-shaped balloon (62). The opportunity for further testing developed during the Joint Army-Navy Logistics Over-the-Shore (LOTS) tests, when a test of the balloon system as an alternative to other more convential discharge methods being developed in this operation was conducted (62). The LOTS tethered balloon test-demonstration was funded from NAVMAT and NAVFAC Exploratory Development funds and Army MERDC funds.

This test was to be a follow-on to work that had been performed in Oregon where RML had conducted a successful test series demonstrating that the military adaptation of the balloon transport system was feasible and where coefficient of drag data measurements had proved inadequate. The specific objectives developed for the test were (63):

1. Evaluate the balloon transport system for discharging containers ship-to-shore (S-T-S) from a containership moored offshore.

2. Evaluate the balloon transport system for discharging containers ship-to-lighter (S-T-L) from an offshore moored containership to a lighter alongside.

3. Develop coefficient of drag data and other technical information needed for further development.

4. An unstated objective was to provide additional visibility to the tethered balloon system as a discharge system (62).

b. System

Original plans called for the use of a new, 630,000 cubic-foot natural-shaped balloon; however, when

the zipper (a new design) failed in a 45-knot wind, this balloon was replaced with a 530,000 cubic-foot balloon. This balloon, a natural-shaped logging balloon, had a free lift at sea level of approximately 24,000 pounds and was able to handle a gross payload of 17,000 pounds (8.5 tons). Gross payload consisted of cable weight, the MILVAN, its contents, and a spreader bar, if used. The balloon was 99 feet in height and had a diameter of 119 feet.

The main winches (yarders) weighed approximately 90,000 pounds each, were single drum units with a speed capability of 1500-1800 feet per minute, and held up to 8000 feet of one-inch steel cable on the drum. Cable tension-measuring equipment provided the operators a constant visual readout of cable tension.

Simulated, non-self-sustaining containerships used were the Navy LST 1180 and the Army BDL 1. The cargo hatch on the LST was fitted with a mockup of a container cell. This cell provided space for stacking two 20-foot containers. Five additional containers were positioned on the deck aft of the hatch. The BDL had no simulated container cell and was used during ship-to-shore operations only as a floating platform.

c. Shipment and Preparation

The balloon and yarders were provided by the same contractor who provided equipment for the previous tests. This equipment was shipped by rail from Eugene, Oregon to Little Creek, Virginia, a trip requiring three weeks. Shipment delay was encountered when the yarders which were loaded on

flatcars were too high and wide for normal freight routing and required special attention throughout transit. This factor is an important consideration in the potential deployability of similar units not permanently stored in port areas.

The most critical portion of the operation was balloon inflation. During the first 30 minutes of the inflating process, wind velocity parameters were established by the contractor (the balloon owner) at eight knots or less. The actual layout, assembly, and inflation of the balloon required nine hours (13).

d. Testing the Ship-to-Shore (S-T-S) Configuration

In preparation for the ship-to-shore phase of the test, the BDL and LCU's containing yarders were anchored approximately 700 yards offshore and hooked together in the configuration shown in Figure 34. A careful comparison of Figures 34 and 19 will reveal three significant differences:

1. The single yarder of the logging industry with its two independently-operated winch drums and ground return block assemblies for the haulback line has been replaced with two independent winches located at each end of the horizontal distance over which the system is designed to operate.

2. A flying Dutchman line and winch assembly has been added to the seaward end to allow lateral movement.

3. The system is now controlled by voice radio link coordinating the actions of the three independent winch operators, as opposed to the positive control of the single winch operator.

Once the seaborne components were in position and hooked

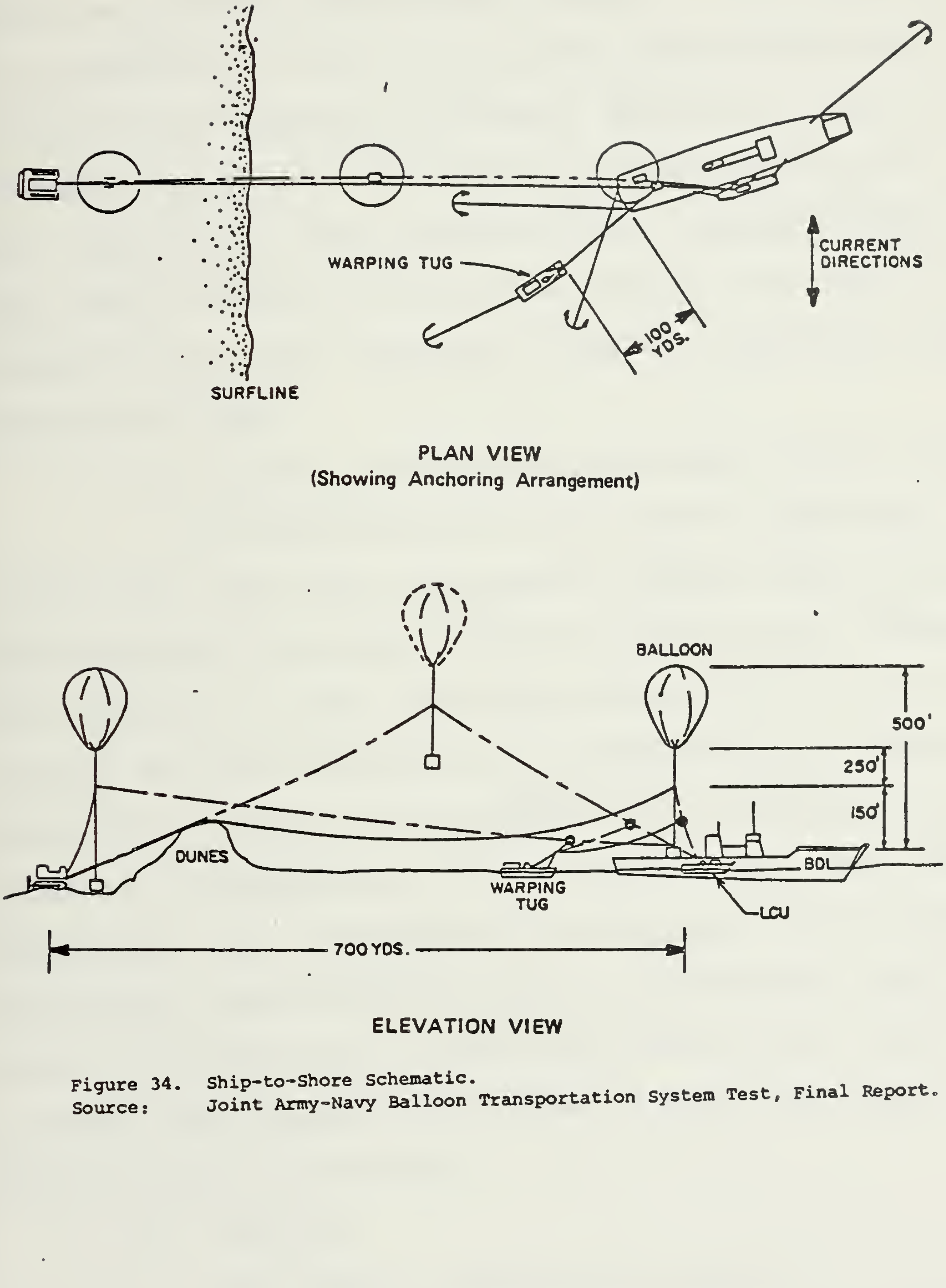


Figure 34. Ship-to-Shore Schematic.
Source: Joint Army-Navy Balloon Transportation System Test, Final Report.

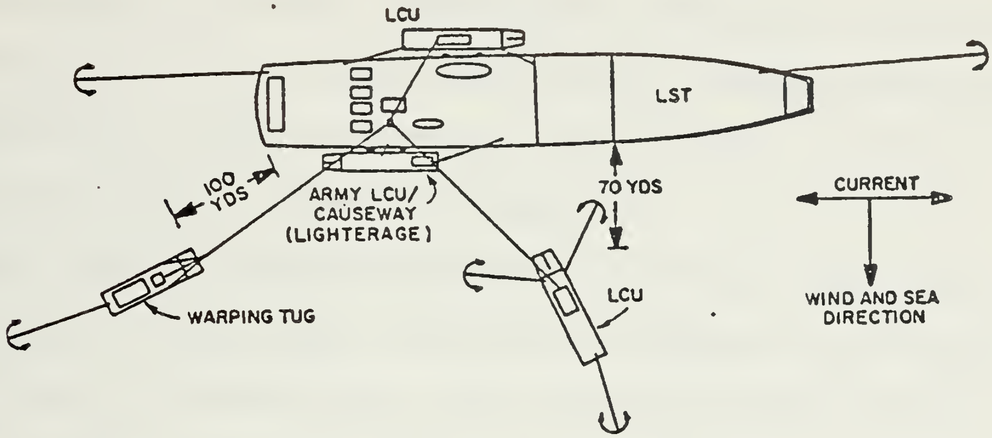
up, the offloading of preslung containers from the BDL was accomplished with an average cycle time of 7.5 minutes using slings. The use of a spreader bar (a square metal frame suspended from the balloon and attached to the upper corner of a container to lift it) required much more precise positioning of the balloon for hookup; therefore, this element increased the cycle time to 11.5 minutes and made the task more sensitive to wind and seas (63). Throughout the operation, ship movement within the anchoring scope made it necessary to halt the operation, unrig the equipment, and reposition the BDL.

e. Testing the Ship-to-Lighterage (S-T-L) Configuration

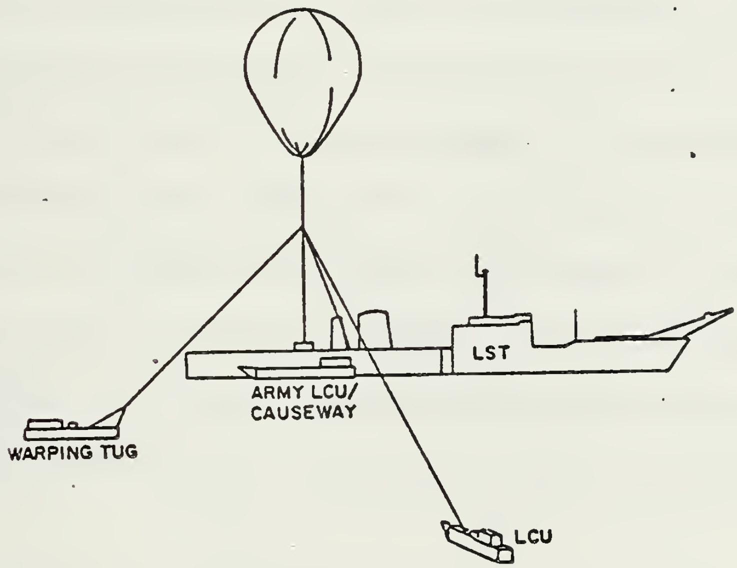
In preparation for the ship-to-lighterage phase of the test, the LCU's carrying the yarder winch assemblies were anchored or secured around the LST and BDL (Figure 35). The objectives of the test were either to pick up the containers from the afterdeck of the BDL and place them in the lighterage alongside or to extract the containers from the simulated container cell in the LST hold and place them in lighterage. The retrograde of containers, the reverse of offloading, was attempted with more difficulty being encountered. In this test, as with the previous one, the use of spreader bars required more time, and they were more difficult to handle accurately.

f. Results

The balloon system as it exists in the logging industry combined with existing Beach Group assets in the configuration tested does not constitute a ready-made mili-



PLAN VIEW
(Showing Anchoring Arrangement)



ELEVATION VIEW

Figure 35. Ship-to-Lighterage Schematic.
Source: Joint Army-Navy Balloon Transportation System Test, Final Report.

tary system for container offloading. It does, however, have the potential for container offloading.

Although not tested, the balloon transport system has the potential for over-the-surf aerial causeway application in offloading causeway ferries, lash barges, or other craft, when configured as shown in Figure 36.

The balloon transport system, as tested, exhibited the following sensitivities: initial 30 minutes of inflation, eight knots; disconnection from ground mooring pad and launching to flying altitude, fifteen knots; system operation, 22 knots (60).

Mooring and anchoring the LCU's or warping tug winch platforms carrying the yarders on the seaward end of the system was difficult and time-consuming. The system required positioning and holding the craft with an accuracy which could not be guaranteed with the craft's conventional mooring system (i.e., anchors versus preset mooring points). The type of ship and craft moorings employed during the ship-to-lighterage test was not acceptable for a balloon transport system.

C. CURRENT STATUS AND REVIEW

The use of a tethered balloon system as an alternative offloading technique has been impeded by doubts of its military worth. The concept of the balloon transport system has been demonstrated to be feasible, however, in both the mountain forests of Oregon and port operations of the Middle East, indicating the true measure of the potential possible with tethered balloons. All military feasibility

Figure 36. Potential Balloon Transfer System Rigged in an Over-the-Surf Aerial Causeway Configuration.
Source: Air Force Range Measurements Laboratory, Balloon Feasibility Study.

studies, experiments, and tests involving the use of a tethered balloon system have, without exception, been concluded on a positive note. Evidence exists that the tethered balloon is comparable in vulnerability to the crane and even less vulnerable than the helicopter (50). The survivability of the balloon is attributed to the fact that it loses lift slowly when punctured, usually giving the operator time to complete one or more cycles before field repair becomes necessary.

It is important to keep the proper perspective when evaluating the results of the military balloon experiments. In all cases these experiments used system components which were designed for very specialized application in a totally different environment from that for which they were intended. The high degree of success of these components indicates a real potential beyond the mere test figures or observations reported.

The military tethered balloon technology which was so successful in the balloon applications of World War II was inadequate for direct use in commercial applications. It would be impractical, therefore, to expect the balloon technology of the logging industry to transfer directly back to the military application without further refinement and development.

The system requirements originating from the services and developed by ARPA (see page 110) represent the most stringent of the category requirements submitted. For example, the requirement to discharge containers from up to five miles

originated in the Army; the Navy supports Marine Corps doctrine requiring a distance of only one mile. Consequently the first Joint Army-Navy Test can be considered a success from the Navy's point of view because it offers documentary evidence that all Marine Corps requirements could be satisfied using a balloon transport system to discharge containerships carrying assault follow-on echelon cargo.

The tethered balloon system employed for the Joint Army-Navy Test was not a prototype of the system that would be required for a military logistics role. It was instead an assemblage of available existing equipment intended to assess concept feasibility, limitations, and obtain technical data that might be required in further development. This test identified a major weakness of the tethered balloon system to be wind sensitivity (see page 138). This sensitivity should be further elaborated and analyzed if completely accurate conclusions are to be drawn from the test data.

It is important to realize that several factors had major impact on the wind sensitivity of the balloon system used in the Joint Army-Navy balloon transport system test (60).

First, the system originally intended for testing utilized a new, modern 620,000 cubic-foot balloon which had an installed passive ballonet designed to increase the balloon's ability to retain its shape and prevent dimpeling. This new balloon, however, deflated due to a faulty zipper located on the lower portion of the envelope and was replaced with an older, 530,000 cubic-foot balloon that was similar to the balloons used a decade ago in the pioneering efforts that

first proved natural-shaped tethered balloons were practicable for use in the logging industry.

Second, throughout the various operations attempted, mooring of the LST/BDL-simulated containership, LCU, and warping tugs in the operations area proved to be difficult and time-consuming. In fact, operating the balloon transport system at sea "required positioning and holding of these craft within tolerances less than those possible with their conventional mooring capabilities; i.e., anchors--not preset mooring points" (60).

Third, because leased equipment was used, balloon operations were approached cautiously; and, as a result, these operations do not necessarily represent what might have been attempted if government-owned assets had been used (60).

It is quite possible that the reported results might have been different if the new 620,000 cubic-foot balloon had been tested in conjunction with small craft and ships secured to firm, preset anchors such as the new explosive anchoring systems available in the commercial world. Undoubtedly, the inability to adequately secure the small craft and ships contributed to the other difficulties encountered during the test.

Wind sensitivity occurs in four critical areas of operation: inflation, launching to flying altitude, operation, and survivability under conditions exceeding the system's safe operation limits.

The balloon is inflated by introducing helium into the balloon to form a bubble at the top which causes the balloon

to stand straight up in a slack condition. When the balloon is in this slack condition, it is most susceptible to dimpeling and subsequent wind damage. Dimpeling is a condition which occurs when the windward face of the balloon is flattened by the wind's force. The flattened face then expands, and the coefficient of drag is increased to the point where the balloon flops around or is beaten about by the wind and ultimately damaged. Dimpeling decreases as the coefficient of drag decreases; a condition caused by either a decrease in the wind or an increase in the internal pressure of the inflation gas. The aforementioned inflation technique was used in the Joint Army-Navy test, and it was correctly labeled wind sensitive. It is quite possible, however, that future experiments may develop alternative methods for inflation that might be less wind sensitive. For example, launching in higher winds can be accomplished with a technique which exposes as little of the balloon envelope as possible to surface winds during the inflation process. This effort might be accomplished by feeding the balloon through a roller assembly which keeps the uninflated portion of the envelope parallel to the ground. Alternatively, it has been suggested that launch could be accomplished from the deck of a ship which would be free to steam on various courses or headings enabling it to create a relative wind of zero on the ship's deck. Yet another possibility might be to inflate the balloon under a large net that could be stretched tight to eliminate the slack condition of the balloon and the subsequent wind-driven flopping around.

The problems encountered while launching the balloon to flying altitude may be alleviated by launching from a properly prepared mooring site. A pre-prepared mooring site allows circular grounding points to be used to control any balloon tilt caused by wind forces (Figure 22).

The balloon operation phase refers to the period of time during which the balloon is inflated, launched, and actually in the operation of moving logs or containers from one place to another. The sensitivity of the balloon to wind while operating could be reduced by any action which would increase the balloon's ability to maintain its shape. One possible approach to this problem would be the development of an active, internal ballonet system similar to that found in the Family II balloons.

Survivability in extreme conditions is exemplified when the wind conditions are expected to be in excess of those parameters established for safe operation, and the balloon is lowered to ground level and transferred to a pre-established mooring site (Figure 21). During the Joint Army-Navy test the pre-established mooring site was not in the direct path of the balloon; therefore, mooring it required that it be lowered to the ground, hooked to a D-6 or D-8 caterpillar, transferred to the mooring site area, and detached and secured to the mooring site. This evolution was time-consuming and wind-sensitive; it might have been quicker and simpler if the pre-established mooring site had been established in the direct path of the balloon operation so that provision could be made to lower it and directly secure

it to the mooring site. In the logging industry moored balloons have survived winds of over 80 miles per hour in an inflated state at ground level. It can be assumed, therefore, that if accurate weather forecasting could provide advance warning of worsening weather conditions, the military balloon could be similarly moored and would survive high winds. Because rain squalls and thunderstorms are very likely to be accompanied by relatively high wind, the weather forecasting becomes essential. When high winds or thunderstorms are imminent, the balloon must be lowered often, sometimes twice a day when a thunderstorm alert exists.

In summary, it is important to remember that the tethered balloon system tested in the Joint Army-Navy test was not "a prototype of the system that would be required for a military logistics role. It was, instead, an assembly of existing equipment intended to assess concept feasibility and limitations ", and as such it admirably accomplished its goals. The Army-Navy test took existing equipment and proved that the balloon system has high potential for the direct, ship-to-shore container offloading of merchant ships, or other similar applications such as aerial causeway operations.

VI. VULNERABILITY

A. THE HINDENBURG MENTALITY

To the uninitiated, one of the most difficult areas encountered in understanding the potential of the balloon transport system is that of vulnerability and strength. Just how reliable is the system? At the mention of a balloon being used in a serious transportation capacity, all too many people immediately conjure up one of two mental images: first, a toy balloon going "bang" when accidentally punctured. This image is often accompanied by the thought that if a little one goes bang, think what a big one would do. Second, the tragic experience of the young child watching his helium-filled toy balloon going up, up, and out of sight when the child forgot to hold tightly to the string is brought to mind. In a general sense this reaction of concern for safety and loss can be described as "the Hindenburg mentality", a general subconscious feeling that all balloons are unsafe, unreliable, and undesireable. This feeling is due to a mental association with either the balloon as a toy or the spectacular crashes and explosions which plagued the hydrogen-filled airships of a bygone era.

B. LOSSES DUE TO ACCIDENTS

There are many precautions taken -- double tether cables and other safety factors -- to prevent the loss of working balloons. In fact, in over ten years of development and operation, there is not one single recorded accident or in-

cident resulting in the loss of an inflated balloon by escape.

Another facet of the general apprehension is the fear of the balloon bursting or exploding; however, this occurrence is technically prevented by the low-pressure characteristic of large balloon systems where the pressure of the inflating gas corresponds very closely to that of the surrounding atmosphere.

Leakage or damage from over-pressurization is also minimal. Calculations have shown that a large balloon with a hole at the top one foot in diameter would require approximately eight hours to lose enough positive buoyancy to become neutral (64).

In the logging operations of the Pacific Northwest, the balloons have proven to be irresistable targets for hunters, and periodic routine examination of these balloons for the wear and tear of daily use has indeed revealed many punctures from high-powered rifle bullets (52). The lifting efficiencies of the balloons were not affected, however, nor did the rifle fire prove to be a safety hazard. In addition, use of helium rather than inflammable hydrogen has eliminated the fire and explosion hazard.

C. LOSSES DUE TO NATURAL CAUSES

1. General

The conclusion should not be drawn, however, that balloon systems are indestructible. Anything that could tear a large gash or opening in the balloon envelope could

disable the system until repairs were made. The greatest dangers to the tethered balloon are not those commonly thought of, however, but rather those that involve the natural elements -- wind, snow, and lightning. The control of these factors is critical to the survival of the tethered balloons.

2. Winds

Winds cause problems during inflation, launch, and flight. Inflation in winds in excess of 10 miles per hour cannot be accomplished. If the balloon were fed through a roller assembly which kept the uninflated portion of the envelope parallel to the ground, however, it might be possible to extend the inflation parameters.

The main problem caused by wind, during both inflation and flight, is the flattening of the windward face of the balloon creating the dimpeling effect. As the wind velocity increases, the dimpeling effect expands, and the coefficient of drag increases to the point where the balloon becomes either uncontrollable by the associated ground equipment or unstable. Gusting winds at 20 miles per hour hamper operation, and at wind velocities above 25 miles per hour, the system is inoperable (65).

3. Snow and Ice

Snow and ice conditions do not occur as often as unfavorable wind conditions, but they cannot be discounted since both can add additional weight to the balloon thereby decreasing the efficiency of the system. Tethered balloons can be swept free of snow with brooms or shaken to loosen

the snow accumulation (50). Ice, however, is another matter, and it can, in extreme weather conditions, stop operations altogether (50). Although it is possible for deicing fluids and skin-heating systems to be developed to overcome both these conditions, present research in this area is not being conducted. The problem is not considered severe enough to the tethered balloon systems now in use to warrant the effort and expense. With the buoyant airships similar to the Goodyear advertising blimps, however, snow and ice problems can become crippling parameters that can prevent the use of a dirigible for any purpose. In an exposed situation this type of airship could conceivably be crushed by the weight of snow.

4. Lightning

Lightning is as severe a problem as wind for the balloon transport system. The tethered balloon is potentially susceptible to this hazard because the tether can act as a grounded conductor. It is estimated that a tethered balloon flying at an altitude of 500 feet will be struck by lightning 2.2 times per year. As the altitude increases to 700 feet, the estimated incidence of lightning strikes increases to approximately eight strikes per year (28).

Protection from lightning is accomplished by controlling the point of initial strike contact, and this is achieved by mounting a small, three-meter tower on top of the balloon at the highest part of the balloon envelope. This air terminal is attached to an aluminum plate approximately three meters

in diameter which serves two purposes: first, it provides mechnical support for the tower; and second, it provides initial, high-conductance distribution for the lightning current. The mounting plate is separated from the envelope fabric by a heat shield, and it is attached to at least four large-gauge conductors radiating outward from the plate and running around the balloon to the tether (Figure 37).

Final protection for equipment is provided by grounding the tether as close as possible to the point where the tether enters the winch. The tether and winch are connected either to a low-resistance earth ground or to the hull of the ship (28). It is quite possible that a total ground would be impossible to achieve, since a structure grounded through a very low resistance can momentarily rise to high potential as a result of the effect of the rapid current rise time (typically, 1.5 microseconds) inherent to lightning and a typical ground cable inductance on the order of one microhenry per meter (28). For this reason it is essential that a protective enclosure be provided for personnel who absolutely must remain near the winch. Probably the person most endangered in the case of a lightning strike transmitted down the tether is the winch operator. His position should be fully enclosed in a protective structure which constitutes an equipotential surface but does not interfere with the operation of the winch (see Figure 20). Although there have been numerous recorded incidents of lightning striking tethered balloons, this protection system has prevented the loss of life as well as damage to the balloon system (50).

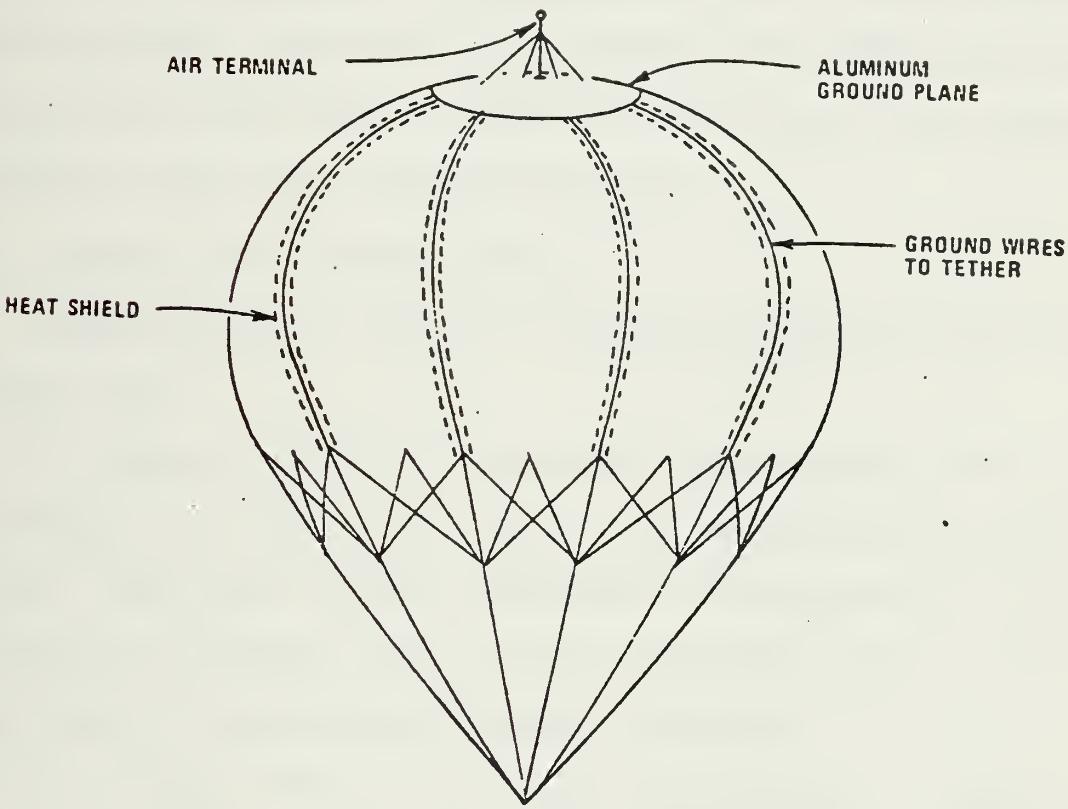


Figure 37. Balloon Lightning Protection System.
Source: Air Force Range Measurements Laboratory, Balloon Feasibility Study.

This does not imply that the balloon is safe to operate in storm conditions, and until more is understood about the lightning threat and associated safety precautions, prudent operational procedures would probably include ceasing operations during storm activities. It should be noted, however, that this constraint is not limited to the balloon transport system alone. Throughout the recent Joint LOTS exercises, operations were stopped and all crane booms were lowered whenever there was shower activity.

D. LOSSES DUE TO ENEMY ACTION

Three types or levels of balloon system kill may be defined (50):

1. "Type A Kill" is the sudden catastrophic kill resulting in the complete loss of the balloon system capability. Since the system components are separated, it may be possible to salvage some of the components, e.g., the winches, even if the balloon envelope is lost.

2. "Type B Kill" is a rapid degradation of capability requiring an immediate halt in operations and repair of the damaged component.

3. "Type C Kill" is a slow degradation of capability in which the balloon system can continue operations until a convenient time for repair.

The system component of most immediate interest in the vulnerability study is the balloon envelope itself. If this envelope is punctured by enemy action or improper handling, the inflating gas will escape and eventually the balloon will lose its buoyancy. The gas release, however, is not a sud-

den rush but rather a slow, steady loss. This degree of damage would therefore be classified as Type C, or at most Type B if the puncture created a big enough hole. The balloon would have to be brought down to be patched either when convenient (Class C) or immediately (Class B). In either case the damage leads to inconvenience and loss of time, but it is not a permanent loss of capability.

As gas escapes, the volume contained by the balloon envelope is necessarily reduced. When this occurs, the balloon changes shape and sags. Additional air flows in at the bottom, reducing the effective buoyancy and pressure distribution across the envelope. The lower pressure then induces a decrease in the rate of gas escape.

A hole area of 0.1 square foot is probably the maximum puncture that would be sustained in an attack by small arms. This corresponds to 73 9-mm bullets, each punching two cross-section holes in the envelope, or one 2.75-inch rocket punching two full-sized holes. Gas escaping from these holes would require about 20 minutes to effect a loss of 1000 pounds, allowing sufficient time to complete a lifting cycle, lower the balloon, and repair the damage (50).

The size of the hole punched in a balloon envelope by a moving projectile is dependent on the projectile shape, size, and velocity as well as material elasticity and strength and the surface characteristics of the balloon. Punctures are usually smaller than the projectiles causing them. At the location where the projectile first contacts the balloon envelope, the envelope membrane has initial biaxial tension.

As the projectile passes through the envelope, it is depressed in a curved indentation (Figure 38). The strain and stress borne by the envelope at any point is proportional to the slope of the envelope membrane at that point. Maximum slope, and, therefore, maximum stress will occur at the edge of the region of contact, and initial failure of the envelope will occur at this edge (50). After the projectile penetrates the balloon, the envelope material stretches around the projectile and snaps back to a smaller size.

The shape of the projectile also has considerable influence on the size of the hole (50). If the projectile has a sharp-pointed nose (Figure 38a), the membrane slope and stress will rapidly rise, and the material strength will exceed a small region. The projectile point will pierce the envelope, and the envelope will probably split far enough to allow passage of the projectile. In the event that the split is in essentially one direction, the envelope will close like a curtain after the projectile has passed, leaving only a small hole through which the inflating gas may escape.

Round-nosed projectiles (Figure 38b) create a more concentrated stress on the nose of the projectile, and a small circular patch of envelope is torn away. As the projectile passes through the envelope, it either stretches around the projectile and then snaps back, or it splits to allow passage. If the split is in one direction only, the hole closes behind the projectile. On the other hand, if the rounded projectile splits the envelope in two directions, the resulting hole can be much larger than the projectile.

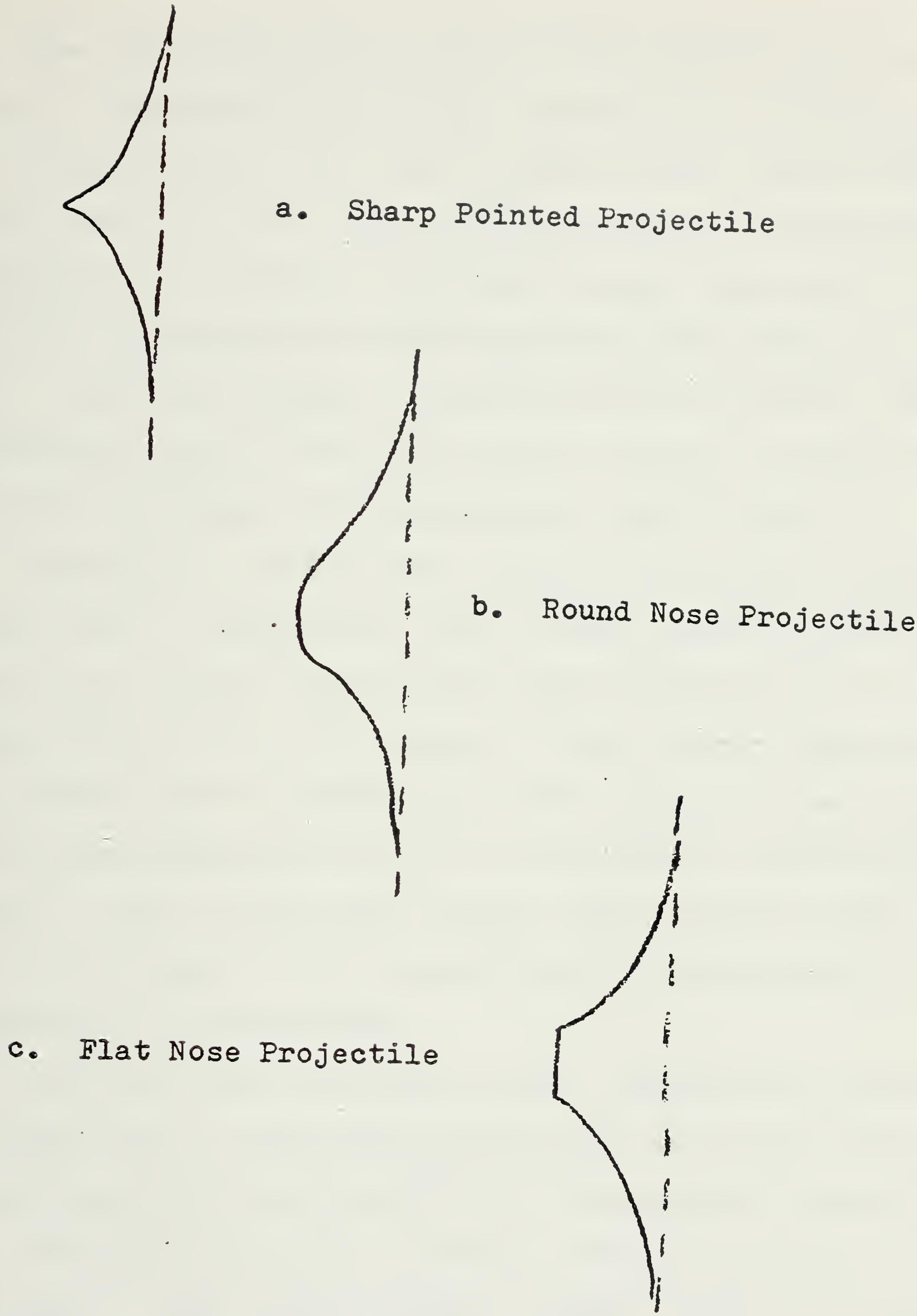


Figure 38. Projectile Penetration Profile.
Source: Naval Facilities Engineering Command, <u>Vulnerability of Tethered Balloon Systems</u>.

When the projectile is flat-nosed (Figure 38c), the material is layed on the nose with essentially no stretching, and the projectile acts like a cookie cutter making circular holes almost the same size as the projectile cross-section. A projectile carrying an explosive charge could open a large hole in the envelope if the triggering mechanism were effective. Since the envelope is non-reflective, however, radar-activated fuses do not work, and the envelope material is too soft to trigger known mechanical impact fuses.

Severing the cables which serve as the balloon tether could cause a catastrophic Type A Kill; however, extra cables in the tether system reduce this probability to a very small factor (50). If desired, a third tether cable between the balloon and the confluence point could be added without suffering degradation due to the addition of significant weight. Even if the tether cables were struck by small arms fire, the damage to the one-inch steel cables would in all likelihood be insignificant.

The winch power and winch control systems are vulnerable to damage from a determined infiltrator and would need to be guarded against this possibility. Considerable damage could be accomplished if the infiltrator actually reached the winch equipment. Sand in the hydraulic fluid, lubrication system, or bearings, or ripped-out ignition wires would be typical saboteur efforts. If this type of damage were to occur, however, the damage is likely to be classified as Type C and would only slow the offloading operation rather than stop it. It should be realized that cranes or other types of conven-

tional cargo handling equipment are also equally susceptible to the types of damage that infiltrators can inflict.

The discharge of containerships with the balloon transport system would not occur during an initial assault time period. It is expected that the beach would be secured, with front lines pushed several miles inland and air control over the beach a reality before the system would be used. Under these conditions it would be operating in an administrative environment, and the threat against it would be limited to those weapons which infiltrators might be able to carry into the area of operations, such as small arms of the 9-mm class, rockets, small explosives, or cutting weapons.

A knowledgeable infiltrator, realizing that little damage would result, would probably not risk firing bullets into the balloon but would concentrate on sabotage damage to the ground equipment. Guarding the ground equipment is therefore necessary to assure protection from this threat. Other infiltrators might fire a clip or two into the balloon, but, as previously stated, small arms fire causes Type C non-serious damage. The balloon envelope could also absorb the impact of two hand-held rockets without significant damage.

Some concern has been expressed that the height of the balloon during transport operations would reveal its location and draw fire from a distance. In the projected military system, the midpoint of the horizontal distance travelled would be the point of greatest balloon altitude. In a balloon transport system designed to operate a distance of one mile, the balloon would be expected to be at an altitude of

500 feet and would be visible for over forty miles from the seaward side (50). Inasmuch as the balloon is not reflective to radar, it would be necessary for enemy artillery to be trained optically; accuracy would therefore be reduced for greater distances thus diminishing susceptibility proportionately. If this visible distance did constitute a problem, however, discharge operations would necessarily be limited to the hours of darkness.

Attack from enemy helicopters or slow-moving aircraft might also be considered. In this case damage would be limited to that caused by 25-mm-sized projectiles or small rockets. This type of damage can be repaired in the field without undue loss of time. Although balloons were used for several purposes during the recent Southeast Asian conflict, no data has been found to date indicating the loss of any of these balloons to enemy action. One balloon system which malfunctioned and drifted out of control was chased by U.S. fighter aircraft which failed to force the balloon down when ordered to do so.

Although it was previously indicated, it should be repeated that none of the threats to the balloon discussed in this section are isolated to the balloon alone. All other conventional systems of cargo handling are also susceptible to these hazards and sometimes even more threatened than the balloon transport system. For example, a serious nick, crack, or break on a member of a crane boom would incapacitate and/or possibly cause a Class A Kill on the crane. Since crane booms are made of high strength (break prone) steel which is hard

to repair, quite possibly repairing a crane boom would require more skill and time than placing cold patches on holes in the balloon envelope. Cranes do not operate in high winds, and aircraft of all types are just as susceptible to enemy action as the tethered balloon. In fact, any threat directed toward the tethered balloon would also be a hazard to other conventional cargo handling systems.

VII. THE TECHNOLOGY TRANSFER BLOCK

A. MISCONCEPTIONS

As previously stated, the major block hampering the development of balloon technology is a state of mind termed the "Hindenburg Mentality" (56). This state of mind can be considered a phobia, and it embraces the attitude that all balloons are unsafe and unreliable. This attitude is associated with the idea that balloons are toys, and who could expect a toy to be taken seriously? The association is further reenforced by today's television beer commercials which portray the hot air balloon enthusiast as a playboy interested only in which variety of beer tastes best.

The most recognizable and familiar examples of buoyant aircraft to the general public are the Goodyear advertising dirigibles. The smallest of them in use today is the Florida-based Mayflower built in 1968, which is 160 feet long, 58 feet high, and 51 feet wide with a capacity of 146,300 cubic feet of helium and powered by twin 175-horsepower, 6-cylinder aircraft engines. The Los Angeles-based Columbia and Houston-based America are sister ships constructed by Goodyear in 1969. They are 192 feet, 1 inch long, 59 feet, 5 inches high, and 50 feet wide, with a capacity of 202,700 cubic feet of helium, and driven by twin 210-horsepower, 6-cylinder fuel-injected pusher type aircraft engines. The most recent Goodyear airship, similar to the Columbia and America, was constructed in Covington, England and is known

as the Europa. It was placed in service in June, 1972 and has performed public relations and public service assignments in eleven countries. All of the Goodyear fleet of airships appear substantial to the naked eye, perform well, and could have furthered the LTA cause but for a series of public information releases stating in part that "...safety is the primary factor in overall airship operation. Although it is possible to fly in some types of adverse weather, the Columbia is not flown in weather conditions of rain and winds in excess of 20 miles per hour" (33). How can a transportation mode be so weather-sensitive and be taken seriously?

B. LACK OF CLEAR DEFINITIONS

Another problem is the aforementioned lack of clear definitions for words and concepts involved in modern airship literature. Many articles and publications seriously attempting to discuss airship feasibility fail to elucidate the different operating principles between the buoyant aircraft and LTA concept.

C. LACK OF KNOWLEDGE

Inside military circles most officers who are students of military history associate balloons with the defeated Zeppelins of history, and, therefore, dismiss their use on the grounds that the balloon is too vulnerable for military operations, even in remote areas. The Navy also has a problem in accepting balloons because the balloon really has no place or home in the Navy. Clearly, it in not involved with

the world of surface shipping, and no less a proponent of air power than Admiral William A. Moffett, USN is quoted as saying in testimony before Congress: "I would willingly sacrifice the purchase of one cruiser for two airships of equal cost, but would not sacrifice any airplane funds and transfer them to the airship fund" (35). One might then ask the question, "Where does the balloon belong in the Navy, or even in DOD?" This question must be answered, because insofar as the development of a balloon transport system for the Department of Defense is concerned, the Army has been tasked to develop it (66), but the Air Force provided its expertise in conducting studies (28) and tests (53) with the Navy taking the lead.[1] In the face of misunderstanding, fear, and lack of knowledge, it is therefore not surprising that the acceptance of the technology is being delayed.

[1]NAVFAC assumed the lead since it is tasked to develop a suitable containership-unloading capability under the provisions of OASD I&L memo of 7 November 1975. The Fort Story tests had to be conducted in 1976 to provide a basis for decisions as to FY 77 expenditures under the Container Offloading and Transfer System (COTS), a Navy Development Program in support of DOD Containerization Master Plan.

VIII. THE NAVAL BALLOON TRANSPORT FACILITY (NBTF)

A. DEFINITION

1. The Naval Balloon Transport Facility (NBTF)

An objective evaluation of the development potential of the military Balloon Transport System (BTS) would lead to a judgment that such a system is technically feasible for use in discharging containerized cargo across unimproved beaches. Further investigation would also disclose the extreme cost effectiveness of the system. This cost effectiveness is illustrated by Table 5 which provides a rough approximate cost in 1975 dollars of cargo handling systems and components commonly associated with logistics-over-the-shore (LOTS) operations.

Item	Quantity	Cost (in millions) (1975 dollars)
LCM-8	1	1
LCU	1	5
Elevated Causeway	1	3
Causeway Ferry (three sections)	1	.8
TCDF (two cranes)	1	1
COD NSSCS (two cranes)	1	1
Tethered Balloon Transport System	1	3.5

Table 5. Logistics-Over-the-Shore Equipment Cost Comparison. Source: Author's Estimates.

The reader's attention is invited to the fact that the tethered BTS shown in Table 5 compares very favorably with

other LOTS equipment now in use or projected for future use. It is significant that the tethered system is a complete system capable of lifting a container from a containership and placing it on shore, while all other equipment listed in Table 5 are merely components of a larger system that must be used in combination to lift the container out of the ship, transport it ashore, and move it beyond the dune line. Therefore, one must recognize the cost effectiveness of the BTS.

Ideally such a system would be compatible with existing surface systems and would operate as a complement to them rather than in competition with them. A realistic target productivity goal for the Naval Balloon Transport Facility (NBTF) would be the capability to discharge 800 containers within a 48-hour period. Therefore, for discussion purposes, the NBTF addressed in this section will be structured around this goal, and necessary assets will be identified.

2. Balloon Design

Future development of existing commercial balloon transport systems will probably involve the use of aerodynamically-shaped balloons similar to the Family II balloons previously discussed. The Range Measurements Laboratory in the Stapleton Experiment (60) has demonstrated that the aerodynamically-shaped balloon could be adapted for use with a tethered BTS. The advantages of the aerodynamic shape are readily apparent; one, it has a lower coefficient of drag as compared to the natural-shaped balloon.* This lower co-

*See Appendix for additional comparison of coefficient of drag between the natural-shaped and aerodynamically-shaped balloons.

efficient of drag translates into more speed and lower horsepower requirements for the accompanying yarder winch systems, making them lighter, and therefore, more transportable. The Family II design also possesses a demonstrated ability to survive under adverse wind conditions.

The disadvantages of the aerodynamically-shaped balloon, as it relates to a NBTF scenario, are more subtle. The aerodynamic balloon requires a more elaborate mooring system, and ground support equipment requirements are more extensive than with the natural-shaped balloon. The complex shape of the aerodynamic balloon makes it more difficult to construct. For this reason, the aerodynamically-shaped balloon would be more expensive than the natural-shaped balloon. One estimate as to comparative cost indicates that it would be at least twice as expensive to manufacture the aerodynamically-shaped balloon as the natural-shaped one (62). In addition, time and expertise requirements necessary to establish, operate, maintain, and repair a BTS are greater if the central component is aerodynamically-shaped rather than natural-shaped. To avoid these disadvantages the NBTF will not use an aerodynamically-shaped balloon.

The NBTF would more than likely be constructed around a 2,200,000 cubic-foot natural-shaped balloon with a net lift of approximately 112,800 pounds (28). This size balloon can be expected to handle the weight of a requirement totalling 30 tons plus the weight of the balloon hardware and the winch cable (28). The balloon will contain an internal ballonet system similar to the newer, natural-shaped balloons now

found in the commercial BTS's used in the logging industry.

3. Operational Concept

Conceptually the NBTF would be structured for ease of transport in a variety of military and commercial ships and would be designed to be quickly set up and operated in one of two basic configurations: the over-the-surf aerial causeway (Figures 39 and 40) and ship-to-shore (Figures 41 and 42).

a. Over-the-Surf Aerial Causeway

The use of the NBTF to discharge material over the surf zone, shore obstacles, rocky coasts, cliffs or poor terrain behind the dune line (e.g., swamps) would provide great flexibility to the Naval amphibious capability. The Over-the-Surf Aerial Causeway (Figures 39 and 40) provides this flexibility. In essence this configuration is similar in operation to the previously shown ship-to-shore configuration; however, the container is not lifted out of the ship. This concept also provides the capability to discharge LASH or Seabee barges, which can be moored to the mooring buoy (Figures 39 and 40) in much the same positions as the causeway sections shown. This configuration is a direct application of the technology developed in the logging industry.

In the ship-to-shore configuration the yarder would be located on either the shore side or seaward end of the rig if a skyline rigging were used, or alternatively a yarder winch could be placed at both ends of the rig, a configuration which extends the operating distance of the system. The exact method of rigging would be dictated by the beach

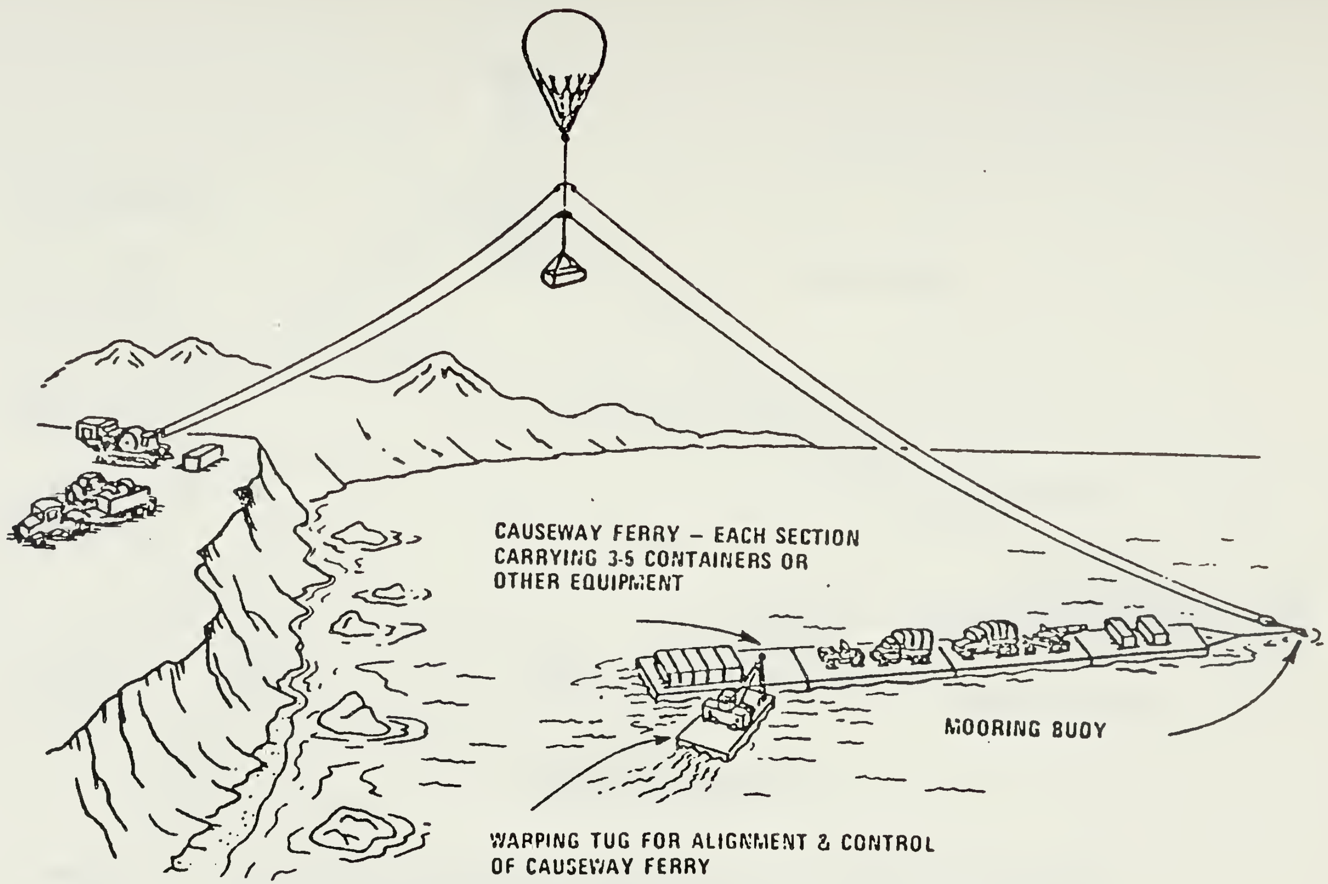


Figure 39. Over-the-Surf Aerial Causeway Concept with Winch Assembly on Shore.
Source: Air Force Range Measurements Laboratory, Balloon Feasibility Study.

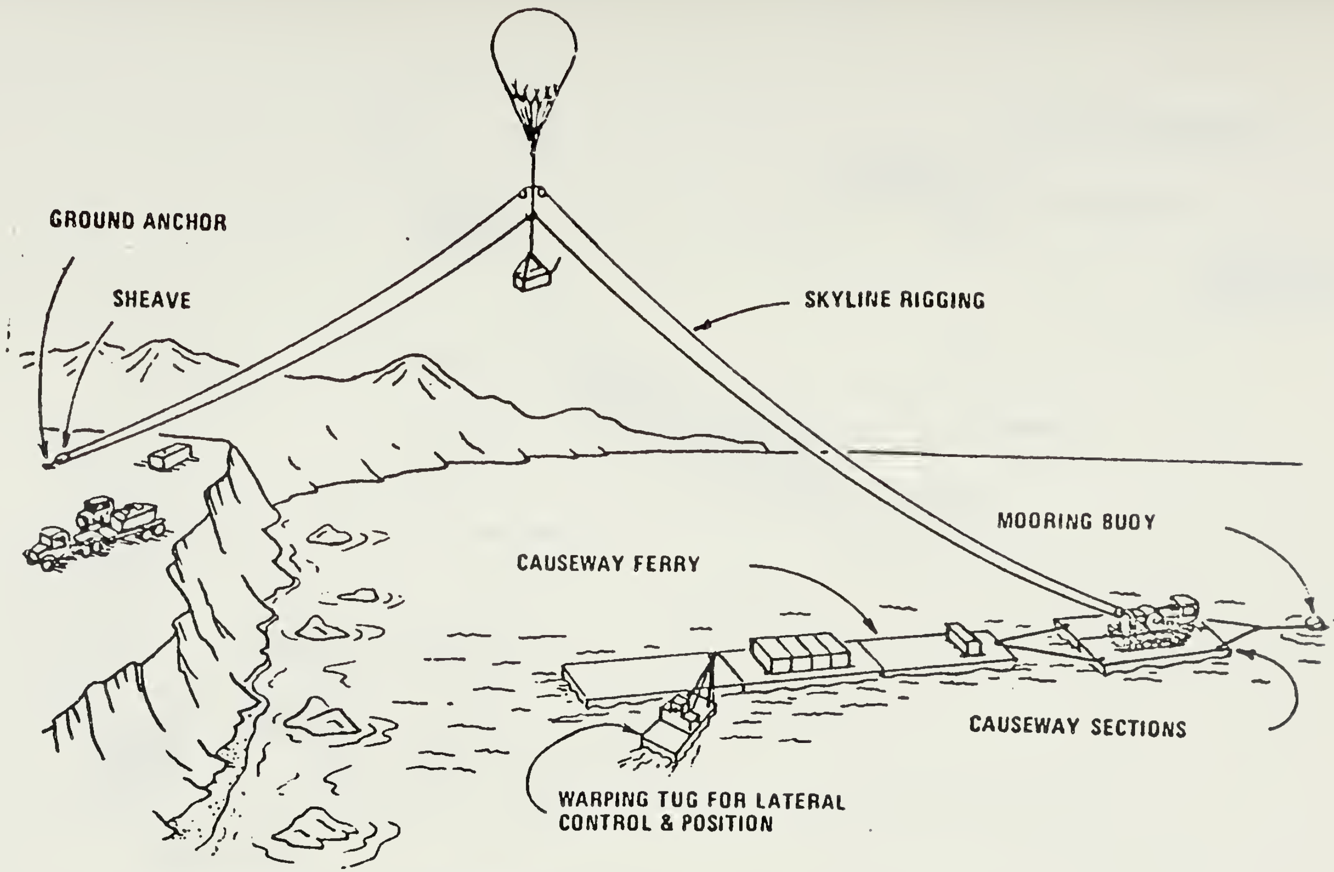


Figure 40. Over-the-Surf Aerial Causeway Concept with Winch Assembly on Seaward End.
Source: Air Force Range Measurements Laboratory, <u>Balloon Feasibility Study</u>.

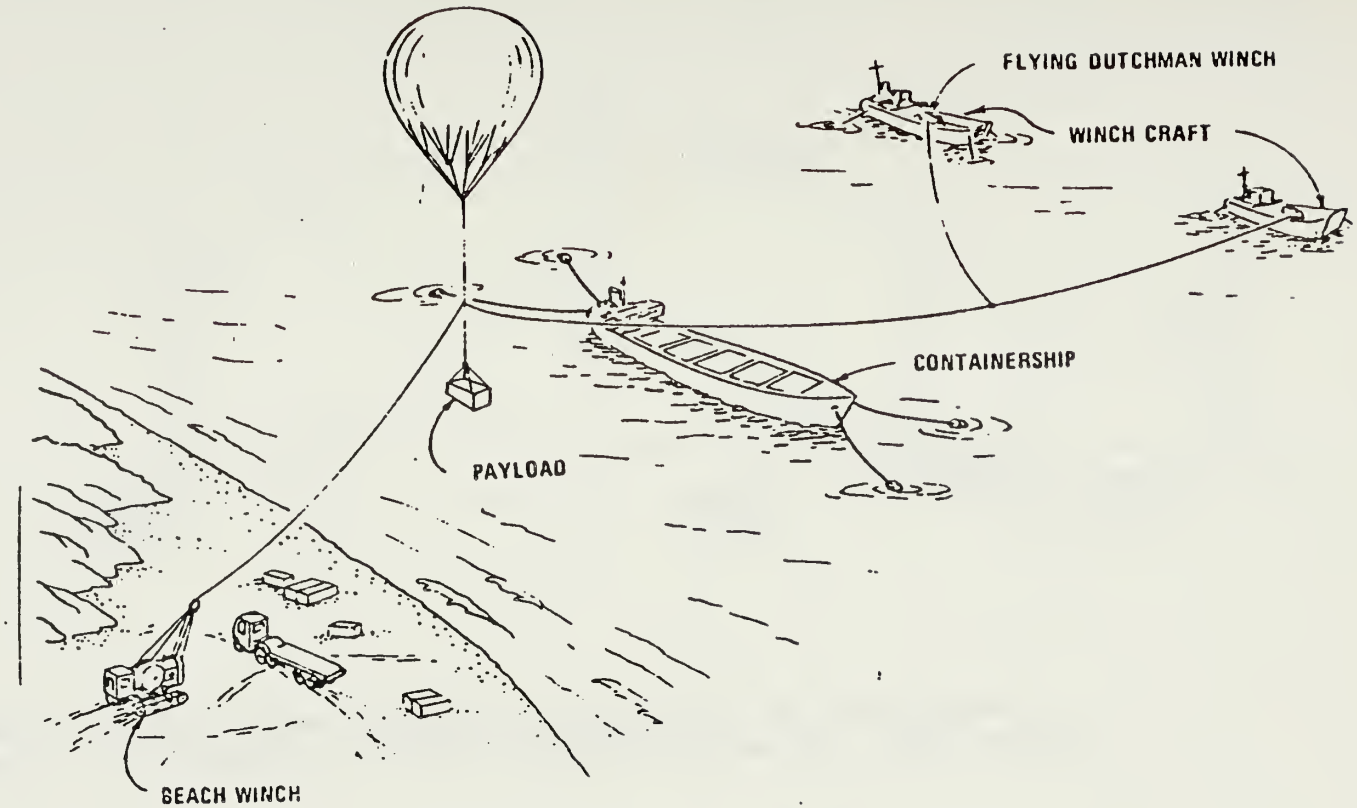


Figure 41. Ship-to-Shore Configuration (Rough Concept).
Source: Air Force Range Measurements Laboratory, Balloon Feasibility Study.

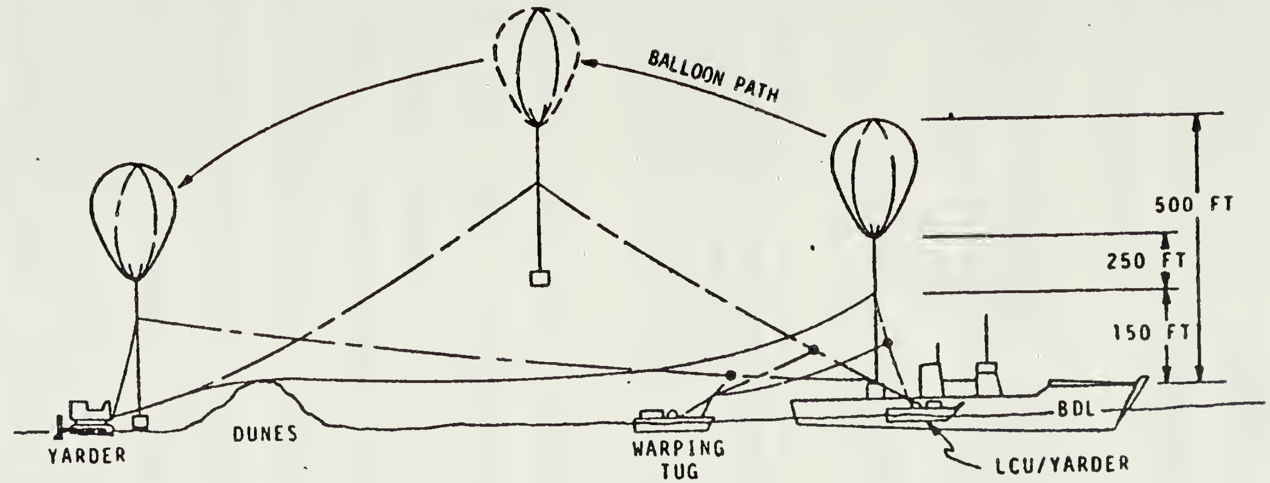


Figure 42. Ship-to-Shore Configuration (As Used in Ft. Story Test).
Source: Joint Army-Navy Balloon Transport System Test, Final Report.

conditions encountered.

The operating distance would be less than one mile, and productivity is estimated by the author to be 15 containers per hour, based on a winch speed of 1000 feet per minute and judgments as to time required for the various actions that combine to produce a completed cycle. Estimated cycle time is shown in Table 6.

Attachment to Container	Transport to Beach	Deposit and Detach Container	Return	Total Cycle Time
1:00	1:00	1:00	1:00	4:00
		Maximum Containers per Hour		
		15		

Table 6. Aerial Causeway Productivity Estimates.
Source: Author's estimates.
Note: These productivity estimates are based on a transport speed of 1,000 fpm (12 mph) over a 1,000-foot distance.

The aerial causeway technique would be particularly valuable if surf zone or beach conditions were such that lighters could not maneuver close enough to the beach to discharge their cargo or where beach crossing would be difficult due to terrain configurations. Lighterage or causeway sections and warping tugs*, available on site, would be utilized to transport containers, general cargo, or outsized cargo from the offshore shipping to the aerial causeway discharge point. The causeway ferries, landing craft, or LASH/Seabee barges, which could be handled equally well, would be towed into position by warping tugs, which could also provide lateral control to the platform being offloaded to bring it under the

*A warping tug is a powered causeway section with the winch and other devices found on small tugs.

hook since coastal currents might be expected to prevail (Figure 43).

b. Ship to Shore

The discharge of containers directly from the containership to the shore by bypassing intermediate staging and handling is the most productive configuration for the NBTF (Figures 41 and 42). In this configuration a cable arrangement would extend from a moored craft, such as an LCU (or preferably a less roll-sensitive but equally-deployable winch platform vessel), to a yarder winch located on the beach. The balloon would be attached to the cable system and be capable of being moved between the ship and shore with its altitude and speed controlled by the yarder winches. Exact displacement or positioning of the balloon over the containership would be accomplished by a flying dutchman winch located in one of the positions shown in Figures 41 and 42. Use of the flying dutchman winch system allows the balloon to be positioned over any container cell along the entire length of the containership, eliminating the necessity for staging the containers in a specific area of the ship which would require the use of cranes. The operational concept involves drawing the balloon down over a container cell, attaching the container, then lifting the container out of the cell for transport to the beach.

To assure effectiveness of the system, it will be necessary to screen containerships used in the logistics resupply pipeline to eliminate those with hatch covers too heavy for the balloon to lift. Some large containerships have hatch

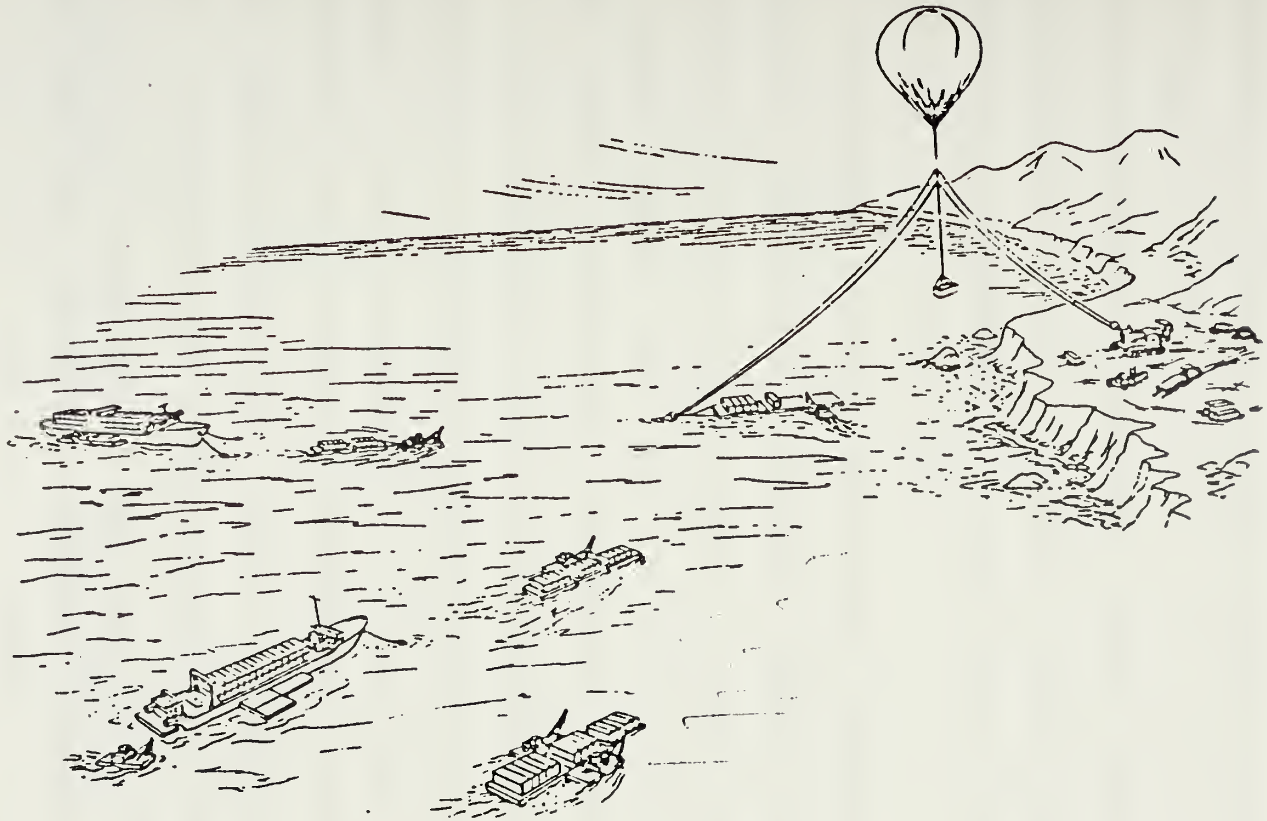


Figure 43. Offloading a LASH Ship with a Balloon Transport Facility.
Source: Air Force Range Measurements Laboratory, <u>Balloon Feasibility Study</u>.

covers weighing as much as 35 tons (62).

The horizontal distance over which a NBTF would operate in a direct ship-to-shore configuration is limited to one mile or less. As the distance increases, the cable weight increases, requiring a larger balloon in turn creating larger drag forces and volumetric lift, which in turn requires a heavier cable to handle the forces involved. Of additional importance are the practical single lengths in which cable can be manufactured and the size of storage drum on which the cable must be spooled.

Using the direct ship-to-shore configuration, a productivity of one 20-foot container each six minutes (10 containers per hour) would require a winch cable with line speed of approximately 2000 feet per minute which is well within the existing technology now in use in the logging industry.

At an operating distance of one mile or less, the productivity of the ship-to-shore system is estimated by the author to be 10 containers per hour, based on a winch speed of 2000 feet per minute and judgments as to time required for the various actions that combine to produce a completed cycle. Estimated cycle time is shown in Table 7.

Attachment to Container	Transport to Beach	Deposit and Detach Container	Return	Total Cycle Time
1:00	2:00	1:00	2:00	6:00

Maximum Containers per Hour

10

Table 7. Ship-to-Shore Productivity Estimates.
Source: Author's estimates.
Note: These productivity estimates are based on a transport speed of 2,640 fpm (30 mph) over a one-mile distance.

At rate of ten containers per hour one balloon could transfer approximately 200 containers in a 20-hour day. A NBTF with two balloons working both ends of the same containership, or separate containerships, could place 800 containers on the beach in 48 hours if no delays occurred.

4. Transportability

The NBTF would be transported to a potential objective area by either military or commercial shipping. The entire BTS assembled for the Joint Army-Navy test at Ft. Story, Virginia would have been easily transportable on a LST or any commercial ship with a jumbo boom. The components and characteristics of the BTS tested by the military are shown in Table 8 (63, 65, 67).

The original balloon (620,000 cubic feet), the hatch box, and the helium trailers were transported over the road by commercial truck to Ft. Story, Virginia without incident. The winches (yarders), transfer vehicle, and miscellaneous support items were shipped by rail from Eugene, Oregon on three flatcars. These cars moved from Eugene to Memphis, Tennessee through the normal railcar dispatching system without trouble; however, in Memphis the cars containing the yarders were classified as "high and wide" (65). The High and Wide classification causes delays because a railcar with outsized cargo moving under a High and Wide classification cannot move on a track where it will be required to pass another train, and special precautions must be taken in tunnels to ensure that the cargo is not damaged. In the case of the balloon tests at Fort Story, this delay was avoided by in-

Item	Dimensions (HxWxL) (Feet)	Quantity	Weight (Pounds)	Origin of Shipment
620,000 cubic-foot balloon	14x7x7	1	8,000	Sioux Falls, S.D.
Single drum logging winch (Yarders)	16x12.25x30	2	90,000	Eugene, Oregon
Transfer Vehicle (Modified D-8 bulldozer chassis)	14x15x22	1	56,000	Eugene, Oregon
Miscellaneous line cable, shackles, etc.	---------	1	20,000	Eugene, Oregon
Hatch box (cargo handling material)	8x8x8	2	10,000	Williamsburg, Va.
128,000 SCF Helium Trailer	11.5x8x36.25	3	57,000	Government Storage Site, Texas
180,000 SCF Helium Trailer	10.5x8x40	1	60,000	Government Storage Site, Texas

Table 8. Components and Characteristics of the Balloon Transport System Tested During the Joint Army-Navy Balloon Transport System Test in 1976.

Source: Flying Scottsman Corporation, Eugene, Oregon.

Note: The components shown were designed for a balloon transport system with a central component balloon of 530,000 cubic feet. The components of the Naval balloon transport facility with its larger balloon would necessarily be scaled upwards in mass and power by approximately one-half. It is technollgically possible to accomplish this and retain physical dimensions and/or disassembly characteristics that would allow shipment and discharge from a LST(68).

curring an additional transportation expense of $16,000 to make up a special train which could be expeditiously and circuitously routed from Memphis to Little Creek, Virginia. At Little Creek the winches (yarders), transfer vehicles, and miscellaneous items were transferred to low-bed semitrailers and moved over the road by military tractors to Ft. Story without problem. After the failure of the original balloon (due to a manufacturing fault in a newly-designed zipper), it was replaced with a 530,000 cubic-foot balloon which was flown from Oregon to Virginia in a deflated state.

Inasmuch as the components (yarder winches and transfer vehicles) used in the BTS tests at Ft. Story were designed for a logging balloon with a capacity of between 500,000 and 700,000 cubic feet, it should be realized that they are not identical to the components that will make up the military BTS with its larger balloon. To handle the increased lift and drag forces which will be inherent in the military system, it will be necessary to scale the components used in the logging system upwards by approximately one-half (68). This is feasible with existing technology and could be accomplished while retaining physical dimensions and/or disassembly characteristics which would allow shipment by rail and LST (68).

The dimensions of the components of the BTS tested at Ft. Story are such that it could easily have been transported to an objective area by commercial break-bulk ship or LST. Figures 44 and 45 show the NBTF being discharged and landed from a LST and a commercial break-bulk vessel.

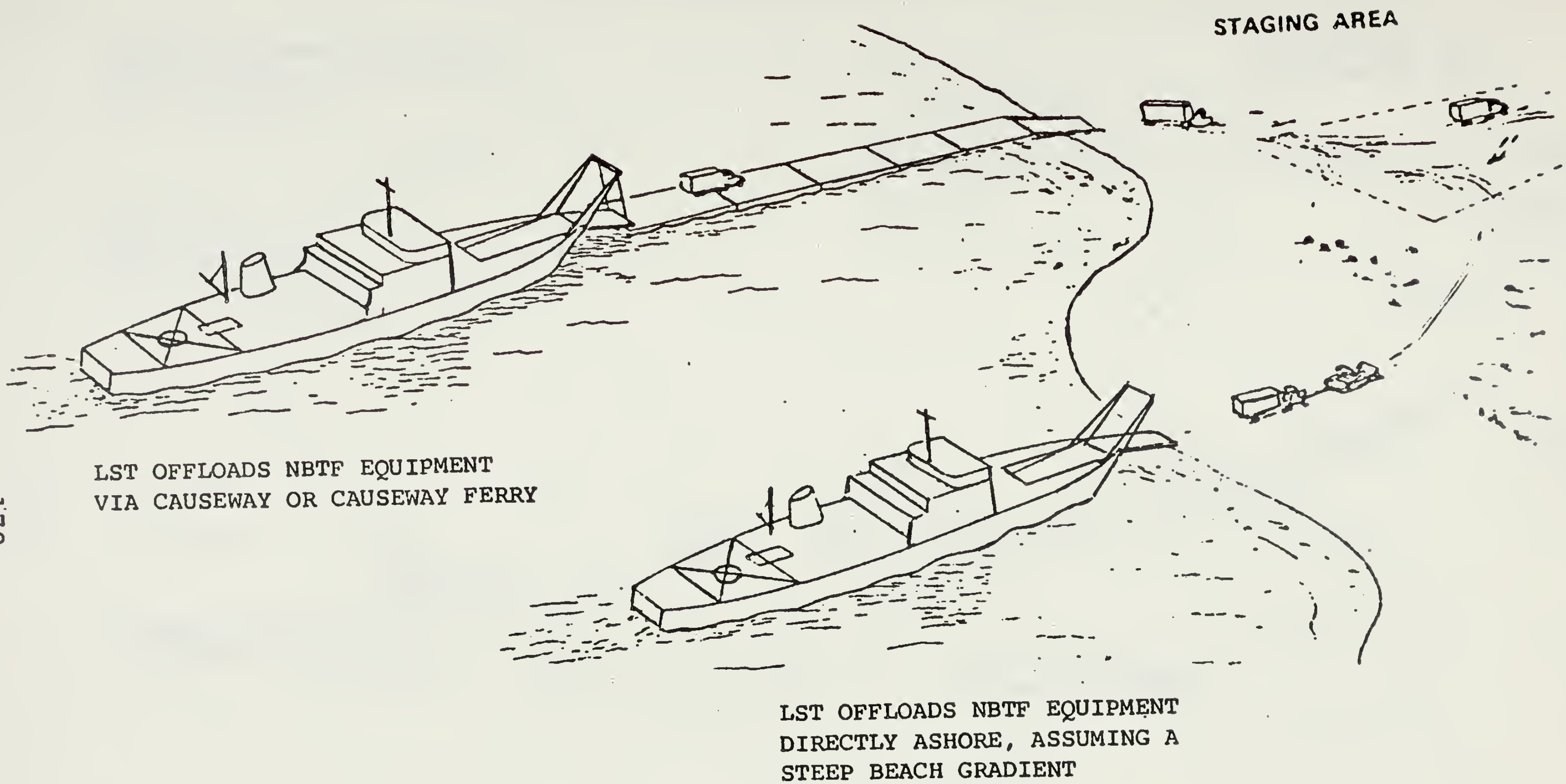


Figure 44. Transporting and Landing A Balloon Transport Facility with a LST.
Source: Air Force Range Measurement Laboratory, Balloon Feasibility Study.

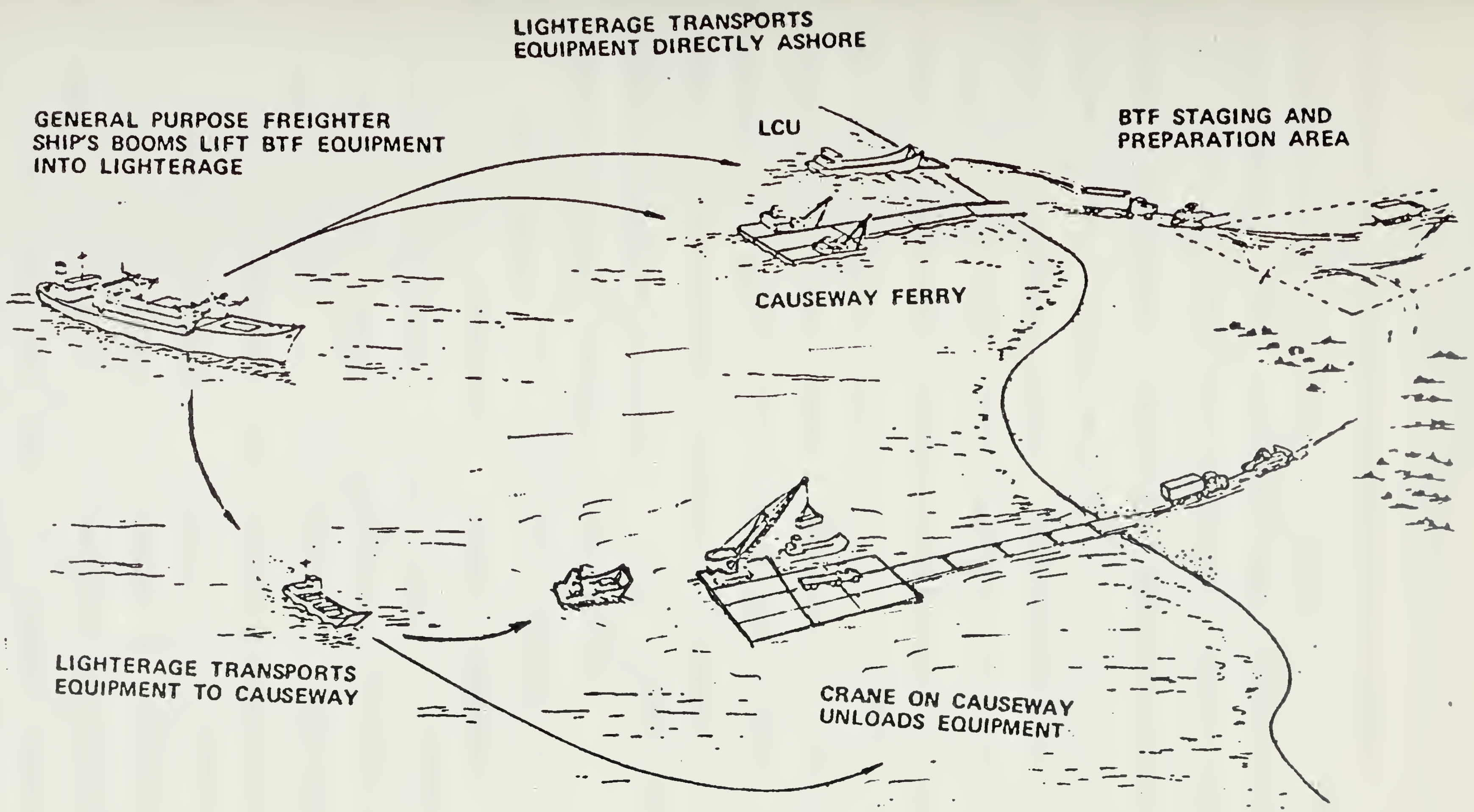


Figure 45. Transporting and Landing A Balloon Transport Facility with A Commercial Break-Bulk Ship.
Source: Author's Concept.

5. Operational Set-up

After the NBTF is transported to the potential objective area by either commercial or military shipping, the system components would be landed directly ashore using NBTF self-propelled equipment and other material handling equipment in use for handling cargo in surface logistics over-the-shore operations. Following the landing ashore, the preparation of the balloon mooring and inflation area with the facility bulldozer begins. This preparatory work includes clearing and levelling the mooring area and removing any stumps, sharp rocks, brush or other debris which could damage the balloon during inflation. A balloon mooring site consisting of dead anchors (Figure 46) buried in a circular pattern is constructed by placing an anchor, called the hard point, in the center to hold the balloon at its base, while outer anchors are attached to the balloon handling lines (a moored balloon is shown in Figure 47).

For inflation the balloon is removed from its shipping container by a forklift or crane, depending on which is available on the beach, and is spread on ground cloths in the mooring area. Helium is introduced into the balloon to form a bubble at the top of the balloon. After the bubble begins to lift the envelope, the balloon is inflated to full volume as rapidly as possible. During the inflation process, the balloon is restrained by a yarder or bulldozer and handling lines. The inflation process must be accomplished in winds of fifteen knots or less. It normally requires five to six hours for the logging industry's natural-shaped balloons.

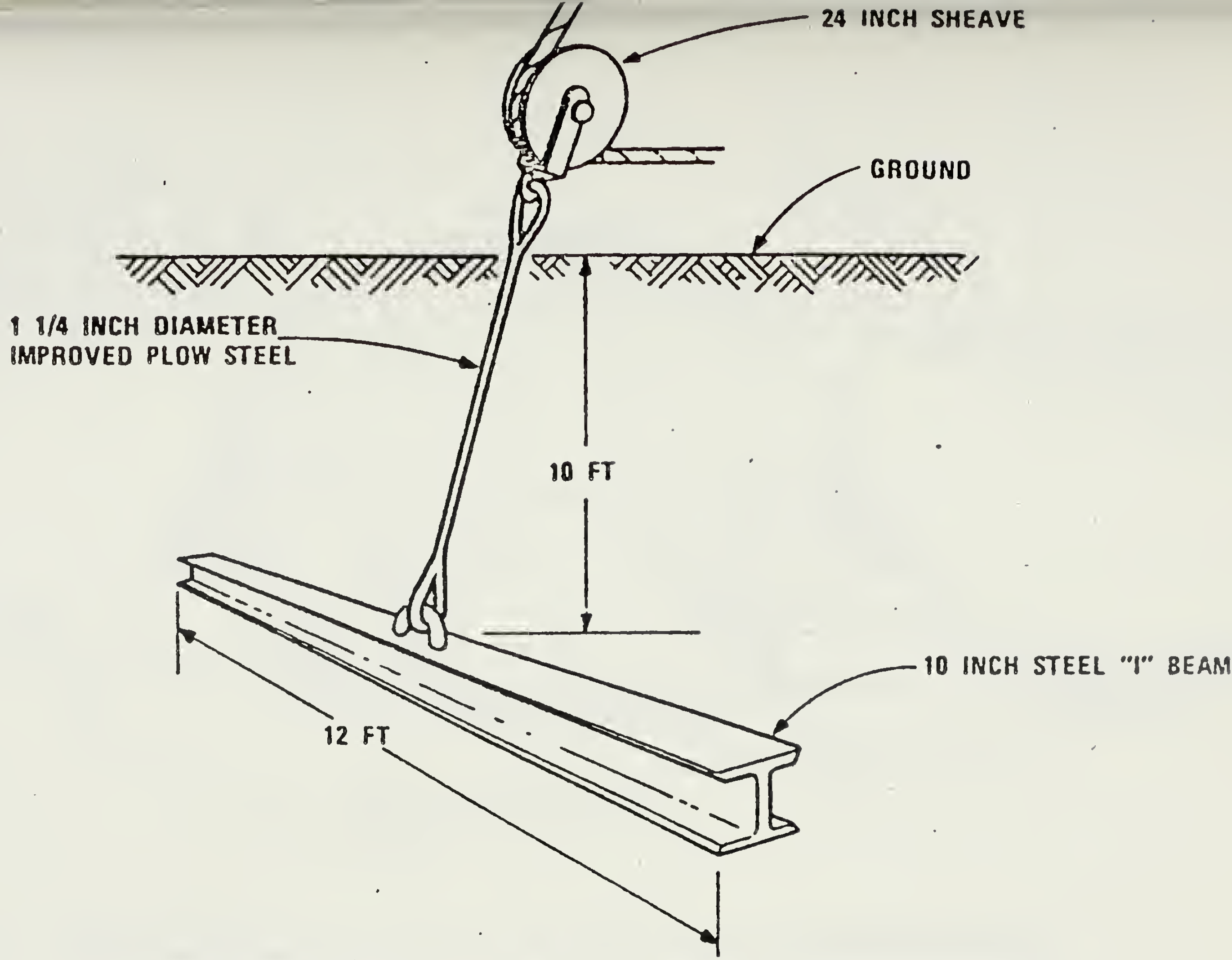


Figure 46. Balloon Anchor System.
Source: Air Force Range Measurements Laboratory, Balloon Feasibility Study.
Note: While the concept illustrated is feasible, the 10-foot depth of the I-beam would be difficult to accomplish. Further engineering development of possible balloon anchor systems would therefore be warranted.

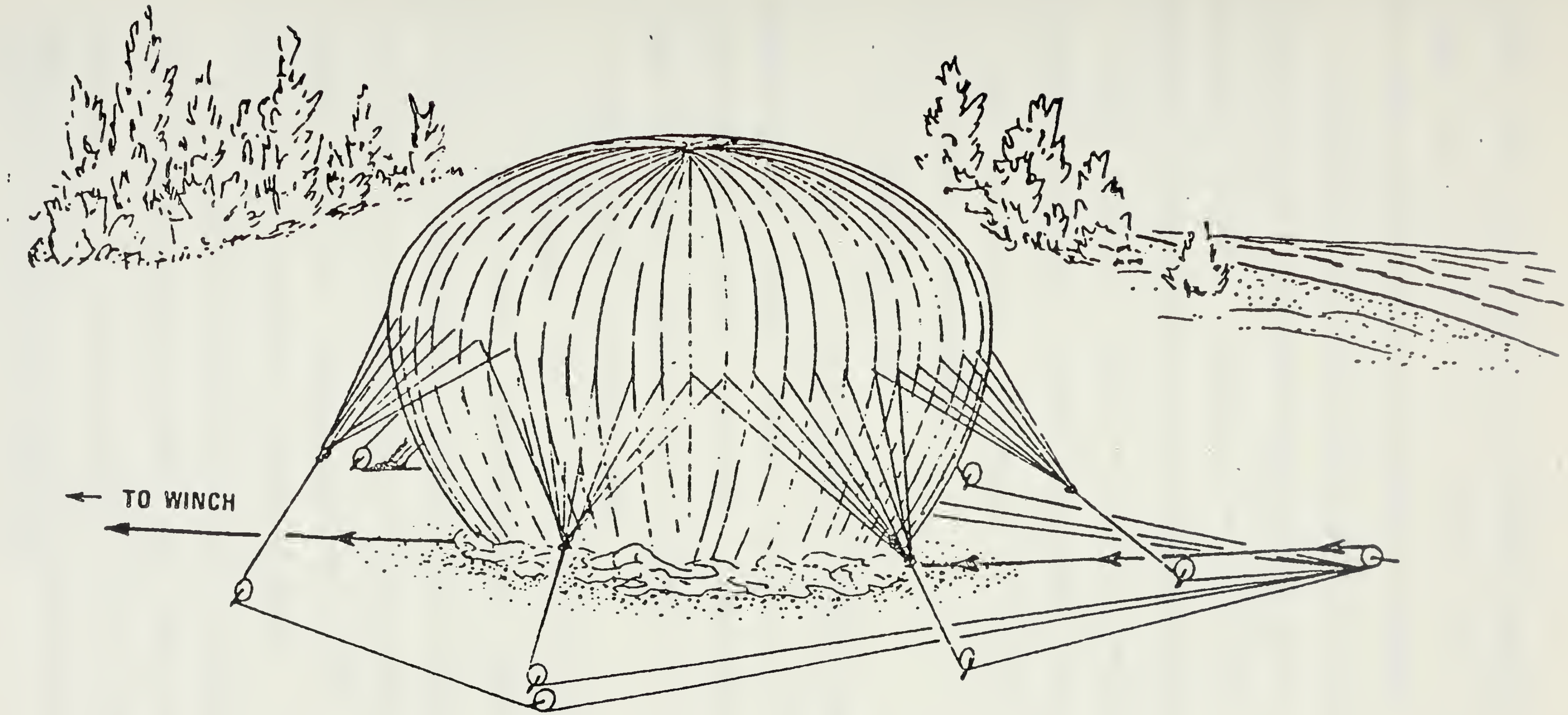


Figure 47. Moored Balloon.
Source: Air Force Range Measurements Laboratory, Balloon Feasibility Study.

After inflation the winch systems (yarders) are deployed to their operating locations, and the cable system is laid out for the appropriate configuration desired.

A balloon operating and rigging crew can be expected to become adequately experienced after one to two weeks of on-the-job training, assuming crew selection is based on a background of heavy-equipment and cable-rigging experience.

Total time for the set-up of an aerial causeway or ship-to-shore operation should not exceed two days* -- one day for site preparation and balloon inflation and one day for cable layout and rigging.

6. Inflation Gas

Helium is the preferred lifting gas for lighter-than-air applications because of its nonflammable nature. Nonflammable helium is available stored in high-pressure tanks in tractor-drawn tube trailers. At least three types of trailers are available (28):

1. A 39-small tube trailer with a capacity of 52,000 standard cubic feet. (Practically, only 40,000 cubic feet of helium is available because some residual helium, ullage, must remain in the tanks to prevent contamination.) This trailer is 25 feet long, eight feet wide, and nine feet high with a gross weight of 35,709 pounds.

2. A second trailer type has a helium capacity of 128,000 cubic feet of which 115,000 cubic feet is actually available. This trailer is 36 feet, three inches long; eight feet wide;

*Based on Ft. Story observations and technical opinions of logging personnel (28, 58, 65).

and 11 feet, six inches high, with a gross weight of 57,000 pounds.

3. The third trailer type has 12 large tubes with a net helium availability of 180,000 cubic feet. The trailer is 40 feet long, eight feet wide, and ten feet, six inches high, with a gross weight of 60,000 pounds.

All the above trailers are designed as integral units, and as such, the tubes are not detached from the trailer bed for shipping. The size of these trailers and their weights would not pose any insurmountable problems in either transporting them or landing them at the objective area. However, an engineering study would be required prior to deployment to confirm that modifications would not be required. The helium itself is compressed to 2300/2800 pounds per square inch (psi) and is ready to be used for balloon inflation without intermediate steps.

Compressors and purifiers are currently available which enable the helium to be reclaimed and repurified during a deflation operation. Storage of reclaimed helium is accomplished using the empty original shipping containers. The 79% pure reclaimed helium can be obtained at a fraction of the cost of new helium, and the stored reclaimed helium is available for reinflation at the BTF operating site or ready for shipment with the facility to a different location (28).

The preferred helium reclamation system is available at a cost of approximately $500,000 (1975 dollars). This system features dual 750 (standard cubic feet) per minute compressors in parallel operation which yield a deflation and

purification capacity of 1500 standard cubic feet per minute for an optimum processing time of approximately 22 hours. The dual compressor system also offers "the added advantage of semiredundancy since if one compressor is down for maintenance, the system will still function at a capacity of 750 standard cubic feet per minute for a processing time of approximately 44 hours." (28)

The cost of helium to the government is $35 per 1000 standard cubic feet at government-controlled helium storage sites, with an additional 15-dollar charge for transportation to east coast ports (1975 dollars). Helium is plentiful: over 40 billion cubic feet are in underground government storage areas, and it is currently being produced faster than it is being consumed (28).

The cost of the preferred helium reclamation system ($500,000) is high*: however, the capital investment can be recovered after six deflations and reinflations of the 1,700,000 cubic-foot balloon. These deflations and inflations of the balloon can be expected as part of the training for operating personnel. In addition the ability to reclaim helium when operating in remote areas far from the helium supply lowers the helium resupply logistics burden.

7. Communications

Operating the NBTF with two balloons will require a great deal of coordination. Ideally one balloon would be on

*The statement that the helium reclamation system costs are high is a relative one. It can be argued, for example, that it costs the same as a 150-ton mobile crane which would be used for the COD or the elevated causeway, or it costs one-half the price of one LCM-8.

the shore unhooking a container while the other balloon would be at the ship hooking up a container. They would then switch positions. The shoreside balloon would proceed out to the ship to receive a container, while the seaward balloon lifted and transported a container to the beach. To ensure the coordination necessary to operate the NBTF, there must be direct voice communication via radio frequency link between the hatch captain on the ship, the discharge site controller, and the yarder operators. The operating frequencies of the communications system should be allocated for this purpose exclusively in the operational plan for the logistics support operation.

The hatch captain on the ship will control the balloon operation via voice communication while a balloon is in the area of the ship. Once the container has been lifted from the cell and the balloon has started its movement toward the beach control shifts, and the discharge site controller controls the balloon system via voice communication as the balloon approaches the beach and discharges its cargo. Control is maintained by the discharge site controller until the balloon has started its return to the ship. At this point control again transfers to the hatch captain. The transceivers on the yarders must have a headset and microphone combination in order to allow the operator the freedom to use both hands and to eliminate the engine noise of the winch.

8. <u>Balloon Transport Facility Hardware Requirements</u>

Using natural-shaped 2,200,000 cubic-foot balloons, the major equipment requirements of a NBTF with one operational

balloon lift system would cost approximately $3,400,000 in 1975 dollars. A facility having two operational balloon systems would cost twice that -- about $5,000,000 in 1975 dollars. Equipment listings are shown in Table 9. This table only identifies the major equipment components necessary to operate the BTS in the two recommended configurations. Estimates of the weight, cube, and dollar cost of the complete table of allowance are included, however, for planning purposes.

9. <u>Balloon Transport Facility Personnel Requirements</u>

The NBTF must be operated by trained personnel, and provision for the acquisition and training of these personnel must be made. The operation and maintenance of a NBTF would require the following personnel for two-shift, round-the-clock operation. Separate figures are shown for the NBTF operating one-or two-balloon lift systems.

Requirement	# Balloons One	# Balloons Two
1. Division Officer/Officer-in-Charge: overall supervision and management responsibility in addition to shift supervision (Lieutenant, 3100 USN/R).	1	1
2. Assistant Division Officer/Assistant Officer-in-Charge: responsible for second-shift supervision (BMCS/Warrant Officer).	1	1
3. Site Supervisor: responsible for directing all operations at the beach landing site (ABMC-E7).	2	4
4. Site Controller: working at site, responsible for directing one balloon system over the beach during transfer of containers; directs staging area personnel, positioning,	2	4

Item	One-Balloon Lift System				Two-Balloon Lift System			
	Quantity	Weight (tons)	Cubic Feet	Cost*	Quantity	Weight (tons)	Cubic Feet	Cost*
Balloon	1 ea	10	1600	400	2 ea	20	3200	800
Cable and Line	1 set	36.5	--	282	2 sets	73	--	564
Yarder (Winch System)	3 ea	210	14700	750	6 ea	420	29400	1500
Site Preparation Vehicle (Bulldozer)	1 ea	60	4260	110	1 ea	60	4260	110
Maintenance Van	1 ea	7.8	1959	25	1 ea	7.8	4260	110
Tractor Truck	1 ea	32.2	3924	38	2 ea	65	7848	76
Semi-Trailer	2 ea	15.5	3438	8	4 ea	31	6876	16
Miscellaneous Support Items and Spares	1 set	42.5	5120	320	1 set	60	7370	580
Sub-total	---	414.5	35001	1933	---	736.8	60913	3671
Helium Trailers	14 ea	420	35840	896	28 ea	840	71680	1792
Helium Reclamation Equipment	1 set	40	3456	500	1 set	40	3456	500
Totals	---	874.5	74297	3329	---	1616.8	136048	5963

Table 9. Naval Balloon Transport Facility Requirements.
Source: Developed from Base Data Produced by Air Force Range Measurements Laboratory, Balloon Feasibility Study.

	and hooking up cargo for outward flight; directs staging area personnel unhooking cargo from incoming flights. Returns operational control of the system to the hatch captain after discharge of cargo (containers) and initiation of balloon's return to the ship (BM1-E6).		
5.	Hatch Captain: working on the ship, responsible for directing the balloon lift system while the balloon removes containers from the ship. Transfers the operational control of the balloon to the beach loadmaster once the container has been removed and started its movement toward the beach (BM1-E6).	2	4
6.	Winch/Yarder Operators: responsible for operation of the winch/yarder equipment (BM2/EO2-E5).	6	12
7.	Hold Boss: responsible for hooking up and handling cargo to and from balloon hookup points on the beach and on the ship (BM2-E5).	4	8
8.	Balloon/Cargo Handlers: responsible for hooking up and unhooking cargo (containers), handling cargo and performing other tasks as assigned by the hold boss. With one balloon working, five at the beach and five at the ship. When two balloons are in operation, five on the beach and ten on the ship/ships (non-rated).	20	30
9	Maintenance Supervisor: responsible to Division Officer/Officer-in-Charge for overall required maintenance of equipment; also directs training programs for equipment operators (MMC/CMC).	1	1
10.	Maintenance Mechanic: responsible to maintenance supervisor for maintenance and repair of equipment including the helium plant (MM2/CM2).	3	5
11.	Documentation Supervisor: responsible to Division Officer/Officer-in-Charge for cargo accountability for all cargo (containers) transshipped (SK1/E6).	1	1
12.	Cargo Checkers: working ship or beach site as necessary to maintain cargo accountability; processing and preparing manifests as necessary (SK3/E4).	4	8

13.	Administrative Clerk: performs administrative duties assigned (YN2-E5).	1	1
14.	Helium Plant Supervisor: responsible for helium plant operation and maintenance (MM1-E6).	1	1
	Total Requirements:	49	81

These requirements total to a manpower requirement of 81 persons for the two-shift, round-the-clock operation of a NBTF with two operational balloons and maintenance of the equipment. Of the 81-person requirement, 51 need to have some training, and 30 could be considered strong-back laborers. A one-balloon operation could be operated with 49 men, of which 29 would need prior training, and 20 could be untrained strongbacks. The annual cost to the Navy of personnel in the ratings identified above are shown in Table 10, and the exact annual personnel costs of the one-balloon and two-balloon NBTF are shown in Tables 11 and 12.

B. FORMATION

1. Placement

When the Navy establishes a BTF, it should be operated by the Navy Cargo Handling and Port Group (NAVCHAPGRU) homeported in Williamsburg, Virginia. The mission of NAVCHAPGRU, as stated in OPNAVINST 5440.73C, is "to provide immediate supervisory cargo handling and port control capabilities to fleet and area commanders for support of naval operations world-wide". Specific tasking also makes NAVCHAPGRU responsible for loading and offloading Navy and Marine Corps cargo carried in support of amphibious warfare requirements. This command is therefore a logical place in which to establish the NBTF, since it will be the command responsible for

Personnel Rank/Rate	Annual Salary*	Total Annual Cost To Government**
Lieutenant	$15,364	$40,788
ABMSC (Aviation Boatswain's Mate --E8)	$11,598	$26,927
BMCS (Boatswain's Mate -- E7)	$10,938	$29,946
BM1 (Boatswain's Mate -- E6)	$8,352	$19,980
BM2 (Boatswain's Mate -- E5)	$7,112	$16,455
BM3 (Boatswain's Mate -- E4)	$6.148	$12,645
MMC (Machinist's Mate -- E7)	$9,938	$31,262
MM1 (Machinist's Mate -- E6)	$8,352	$21,580
MM2 (Machinist's Mate -- E5)	$7,112	$17,574
CMC (Construction Mechanic -- E7)	$9,938	$31,262
CM2 (Construction Mechanic -- E5)	$7,112	$19,039
EO2 (Equipment Operator)	$7,112	$18,980
YN2 (Yeoman -- E5)	$7,112	$16,024
SK1 (Storekeeper -- E6)	$8,352	$20,491
SK3 (Storekeeper -- E4)	$6,418	$12,974
SN (Seaman -- E3)	$5,522	$10,545

*Annual salary less BAQ.(Source: Acme Joint Service Pay Table Effective 10 October 1977)

**Total annual cost to government of various annual personnel costs. (Source: Annual Enlisted Manpower Billet Costs for Life Cycle Planning)

Table 10. Representative Naval Personnel Costs (1975 dollars).
Source: NAVPERS, Occupational Standards Dept., Annual Enlisted Manpower Billet Costs for Life Cycle Planning, 12 Feb 75.
Note: If more up-to-date cost data are necessary, attention is invited to Users Manual, Billet Cost Data, Ref (71).

Billet Description	Quantity	Annual Cost to Government (ea)*	Total Annual Cost to Government
LT	1	$40,788	$40,788
ABMCS	2	$26,927	$53,854
BMCS	1	$29,946	$29,946
BM1	4	$19,986	$79,944
BM2	10	$16,455	$164,550
SN	20	$10,545	$210,900
CMC	1	$25,813	$25,813
MM1	1	$21,580	$21,580
MM2	3	$17,574	$52,722
SK1	1	$20,491	$20,491
SK3	4	$12,974	$51,896
YN2	1	$16,024	$16,024
	49		$768,508

*1975 dollars

Table 11. Annual Cost to Government of Personnel Required to Operate a One-Balloon NBTF (1975 dollars assuming all persons on board are active duty military and least-cost rating is selected where billet description allows choice).

Source: NAVPERS, Occupational Standards Department, <u>Annual Enlisted Manpower Billet Costs for Life Cycle Planning</u>, 12 February 1975.

Note: If more up-to-date cost data are necessary, attention is directed to <u>Users Manual, Billet Cost Data</u>, Ref (71).

Billet Description	Quantity	Annual Cost to Government (ea)*	Total Annual Cost to Government*
LT	1	$40,788	$40,788
ABMCS	4	$26,927	$107,708
BMCS	1	$29,346	$29,346
BM1	8	$19,986	$159,888
BM2	20	$16,455	$329,100
SN	30	$10,545	$316,350
CMC	1	$25,813	$25,813
MM1	1	$21,580	$21,580
MM2	5	$17,574	$87,870
SK1	1	$20,491	$20,491
SK3	8	$12,974	$103,792
YN2	1	$16,024	$16,024
	81		$1,258,750

*1975 dollars

Table 12. Annual Cost to Government of Personnel Required to Operate a Two-Balloon NBTF (1975 dollars, assuming that all persons on board are active duty military and least-cost ratings are selected where billet description allows choice).

Source: NAVPERS Occupational Standards Department, Annual Enlisted Manpower Billet Costs for Lift Cycle Planning , 12 February 1975.

Note: If more up-to-date cost data are necessary, attention is directed to Users Manual, Billet Cost Model Ref (71).

the ongoing cargo discharge function during the assault follow-on echelon phase of a logistics over-the-shore operation. In addition NAVCHAPGRU provides contingency cargo handlers for a variety of commitments in support of Naval operating forces. Locating the NBTF with NAVCHAPGRU therefore has the dual advantage of increasing the capability of the command tasked to discharge commercial ships in support of amphibious operations and makes the NBTF available on a contingency basis wherever it might be used.

2. Establishment

The predeployment configuration of the NBTF would, to a large extent, determine the cost of acquiring and maintaining it. Conceptually, there are several alternative means of acquiring, establishing, and maintaining the capability to operate and deploy a NBTF. These alternatives are:

1. Establish the facility within an existing port area and operate it in support of military cargo operations.

2. Acquire and maintain it in a pre-packaged condition as part of NAVCHAPGRU's Table of Allowance (TOA), which is held as Pre-Positioned War Reserve Material, where it would be ready for use when needed.

3. Establish the facility with NAVCHAPGRU, authorizing the equipment as a part of the onboard Table of Allowance equipment and operate it as a deployable training facility.

4. Acquire it by government funding and operate it by a nonprofit, quasi-governmental service company similar to the Tennessee Valley Authority. This company would be most optimal if directed and operated by the U.S. Forest Service

which would utilize it to harvest government-owned timber. Under these conditions the equipment could be maintained in operating condition and even be replaced as necessary with minimum cost to the government, and, at the same time, the system could be made available to active duty and/or reserve personnel for cargo handling training during a part of each year.

Establishing and operating a NBTF within an existing port area in support of military cargo operations is not without its difficulties. Acquiring the equipment would cost about $3.5 million in 1975 dollars, and 49 new, active-duty billets would have to be created and supported. Although the 49-billet requirement would be mitigated to some extent by a saving of labor in other cargo-handling methods, this saving would probably not equal the new requirement. In addition, current CNO policy dictates that Navy cargo handlers must not displace civilian cargo handlers inside the continental limits of the United States. This indicates that the newly-created unit would of necessity be located overseas. The potential difficulties of locating such a unit overseas or its effect on readiness for further deployment from an overseas site would, of course, need to be investigated at the time the decision is made.

Either locating the facility within NAVCHAPGRU or holding it as part of its Table of Allowance would involve changing the Table of Allowance and purchasing the equipment. A one-balloon lift system would require approximately $3.5 million for initial purchase, and a further estimated $200,000

[illegible]

to prepack and pre-position the equipment. In the event that the equipment were to be placed in NAVCHAPGRU's Table of Allowance as Pre-Positioned War Reserve Materials, no additional active duty personnel would be required. Provision would need to be made, however, for satisfactory training.

Equipment for that training would need to be leased or rented, and it might not be available at locations other than in Oregon. This training requirement for active duty personnel might be reduced by tasking a Reserve Cargo Handling Battalion to maintain the capability of operating a BTF. This option raises the question of how available the reserve personnel might be in an undeclared contingency: their unavailability could lead to reduced capability and a degradation of response time.

Establishing a BTF as a quasi-governmental service company which would allow its equipment to be used a part of each year is an attractive alternative. This option allows the Navy to acquire the capability at minimal cost and provides an opportunity for on-going training of personnel. The maintenance of the BTF by one of the six Reserve Cargo Handling Battalions particularly lends itself to the idea of operating the quasi-governmental public service corporation under the U.S. Forest Service. The Navy and the Forest Service have already cooperated with each other on more than one occasion to jointly fund and develop a lighter-than-air concept (25), and, therefore, this possibility may be more feasible than it first appears. The use of reserves, however,

involves the trade-off decision as to their availability in undeclared contingencies as previously mentioned.

Perhaps the most optimal solution concerning the implementation of the NBTF would involve establishing the NBTF within NAVCHAPGRU and operating it as a deployable training facility. A one-balloon lift capability would require $3.5 million for equipment acquisition and the establishment of six additional billets within NAVCHAPGRU. These billets and their annual cost are listed in Table 13.

Billet	Rate	Quantity	Annual Cost to Government (ea)*	Total Annual Cost to Government**
Site Supervisor	ABMCS	1	$26,927	$26,927
Helium Plant Supervisor	MM1	1	$21,580	$21,580
Maintenance Mechanic	CM2	2	$19,039	$38,078
Equipment Operator	EO2	2	$18,980	$37,960
		6		$124,546

*1975 dollars

Table 13. Personnel Requirements and Annual Cost Estimates Involved in Establishing a NBTF Within the NAVCHAPGRU (1975 dollars assuming least-cost rating is selected where billet description allows choice).

Source: NAVPERS, Occupational Standards Department, Annual Enlisted Manpower Billet Costs for Life Cycle Planning, 12 February 1975.

Note: If more up-to-date cost data are necessary, attention is directed to Users Manual, Billet Cost Data, Ref (71).

IX. SUMMARY

A. BACKGROUND

The military is dependent upon the commercial merchant fleet to transport required tonnage in support of deployed expeditionary forces. Ten years ago commercial fleets were composed of large numbers of highly flexible break-bulk ships. Investment in each ship was limited, and daily operating costs were low. The old break-bulk ships served multiple ports, accommodating small aggregations of cargo, and spent most of their time loading and discharging their cargo. While experiencing high ship-to-shore costs, break-bulk vessels were remarkably flexible, capable of diverting off route carrying any cargo, and serving any port or need without substantially impairing schedules, disrupting shore operations, or adding to costs. These vessels were self-sufficient, interchangeable units. They could replace one another on the trade routes or satisfy military requirements with equal ease. Overhead costs were low so they could stand by offshore, be stockpiled in reserve fleets, or be laid up by private operators without undue financial burden.

The old break-bulk fleet was particularly well-suited to military needs because it had flexibility in terms of both numbers of ships and types of cargo which could be carried. Basically they were designed to carry a large number of small, easily-handled palletized loads and were characterized by labor-intensive loading and unloading methods. The container-

ship is just the opposite: it is larger, faster, designed to handle a smaller number of large (container-sized) loads; and it operates in an equipment-intensive port environment. The new containerships are more expensive, having higher daily operating costs. They cannot be diverted from high-density routes for small allocations of cargo, and they cannot stand by waiting for discharge for long periods of time. Containerships are several times as productive as the break-bulk ships they replaced and have substantially reduced vessel in port-time. The new containerships require enormous aggregations of cargo for optimum utilization, however, and they must be discharged and reloaded expeditiously by shore-based equipment.

Productivity gains achieved by containerships have necessitated handling single, large, heavy loads and have created a loss of service flexibility. The new containerships are fast, intermodal vessels accounting for an everincreasing percentage of U.S. merchant ships ton-mile capacity. It is becoming increasingly important, therefore, to ensure that high speed and fast turnaround capabilities be achieved in military support operations. Future logistics planning must include a provision for rapid offloading and fast turnaround to realize the full potential of the high productivity containerships. Tying up an SL-7 containership in the objective area is the approximate equivalent of tying up 14 C-3/A-2's in terms of annual maximum ton-mile capacity lost (3). Holding vessels for long periods of time in an objective area probably will not be an option in future contingencies.

Recognizing the requirement to discharge containerships in the unimproved environment characteristic of amphibious warfare, the Department of Defense is now developing alternative methods of accomplishing this task. One method currently under investigation is the Balloon Transport System (BTS) developed from technology originating in the logging industry. This system will potentially be capable of lifting containers out of containerships anchored offshore, transporting these containers to the shore, and depositing them in a predetermined location beyond the dune line (Figure 41).

B. COMMERCIAL TETHERED BALLOONS

The use of tethered balloons is not a new idea. They have been used by the scientific community for meteorological purposes since 1784, and they have been used by the military for observation missions almost continuously since 1794. Within the last decade the technology developed by the scientific and military communities in using tethered balloons has been adapted successfully to a variety of commercial uses.

The transfer of this technology began in the early 1960's as attempts were made to use low altitude balloons to lift payloads from inaccessible places. The early attempts involved experimentation with aerodynamically-shaped Army surplus barrage balloons and vee balloons, but little real success was achieved. The real development of a BTS began in the mid-1960's when the Raven Industries developed the natural-shaped balloon for use by the logging industry. The natural-shaped balloon, operating in a tethered system and

deriving its lift from aerostatic qualities, has proved to be the successful central ingredient in a system used to remove logs from inaccessible areas.

The balloon system, as shown in Figure 17, consists of: the balloon; four wire rope-control cables; a large, self-propelled winch assembly; and several ground-mounted trail blocks. When one winch is reeled out and the other reeled in, the balloon travels back and forth across a predetermined path. When both winches are operated in the same direction, the balloon is moved up or down vertically. The present logging system operates across an average distance of 0.5 miles at speeds of over 2400 feet per second. It is mobile and can be relocated easily. Two-shift, around-the-clock operations are routinely conducted with the use of illumination devices. Over the past ten years the system has proved to be highly reliable and has operated profitably.

The balloons which were designed and developed for the BTS are in an inverted teardrop or natural shape. This shape has the advantage of minimum surface area per given volume, and it presents the same size and shape in all horizontal directions. Thus the aerodynamic qualities of the balloon are minimized in wind conditions, creating a more stable lift. These natural advantages are counterbalanced by the disadvantages of the balloon's high coefficient of drag and a sensitivity to wind conditions which prevent operation in winds above 25 knots.

The balloons in use today are over 500,000 cubic feet in volume and 100 feet in diameter. They are made of a coated

dacron material, are inflated with helium, and can lift a payload of 12 tons. Over ten years' experience with the natural-shaped balloon has produced a low maintenance balloon of proven reliability.

All current development efforts involving the commercial BTS have the goal of extending the limits of the system: distance capability, cycle time, high coefficient of drag in the natural-shaped balloons, and system sensitivity to wind and snow conditions. The operational distance is limited to the length of the control cables on the yarder winch drums. At the present time this limit is about 3600 feet. Cycle time is a direct function of three factors: distance travelled, hook-up time, and speed of the winch drums. Hook-up time has been reduced to the maximum possible extent and further decreases in cycle time must now be achieved by increasing winch speeds. High coefficient of drag, inherent in the natural-shaped balloons, translates into increased horsepower requirements in the winch assemblies and larger, heavier cable in the controlling system. Sensitivity to wind and snow conditions place undesireable parameters on safe operating conditions and often result in decreased operations. Currently, positive progress is being made in lengthening the operating distance of the system and in increasing winch speed by developing bigger, faster yarder winch assemblies. In addition, some progress has been made in reducing the wind and snow sensitivity by designing rounded tops for the newer balloons and installing passive ballonets inside the balloons, thereby increasing the balloon sta-

bility. At present no solution has been found for the problem of high coefficient of drag, and the system cannot be considered all-weather due to the limitations imposed by its sensitivity to wind and snow conditions.

Further progress in solving the problems associated with high coefficient of drag and weather sensitivity found in the present commercial systems is unlikely until the design of the natural balloon itself is altered to incorporate aerodynamic features. Although early experiments indicated that the aerodynamic qualities were undesireable, it is possible that this decision may have been made without a real understanding of the factors involved. Using modern analytical techniques the Air Force's Range Measurements Laboratory has developed a new family of aerodynamic balloons which could be adapted to the commercial BTS with dramatic results.

C. THE MILITARY BALLOON TRANSPORT SYSTEM

Development of the military BTS began with the identification of system objectives by the three branches of the military service and proceeded in an orderly fashion from the first preliminary "can we pick up a container with a balloon?" stage to complete testing of the concept in an offshore operation. A brief review of the highlights of this development would include:

1. 1971 -- Development of system objectives and establishment of a funded base for further development.

2. 1972 -- Test Series I: using an onsite logging balloon rig and its crew, the Range Measurements Laboratory con-

ducted the first preliminary tests demonstrating that a container could be handled successfully with a BTS.

3. 1973 -- Test Series II: under conditions similar to those encountered in Test Series I, precision handling and placement was demonstrated in a simulated container cell at various positions of tilt in order to simulate as nearly as possible conditions which might be met in extracting or positioning a container in a moving containership anchored offshore. This test also investigated alternative rigging methods in preparation for transferring the system into an at-sea environment.

4. 1973 -- Test Series III: as a follow-on to Test Series II, this series of tests collected information on exact coefficient of drag values and the related wind resistance which could be encountered in an at-sea test.

5. 1974 -- Stapleton Logistics Experiment: this experiment used an aerodynamically-shaped balloon and modified rigging techniques which significantly extended the potential distance over which the balloon system could operate.

6. 1976 -- Joint Army-Navy Balloon Transport System Test: using existing equipment developed for the logging industry, the concept of handling containers from ships at sea was tested, and an increased understanding of the coefficient of drag for natural-shaped balloons was achieved. Although the test was somewhat limited when the original balloon failed due to a faulty zipper (a new design), it did successfully meet the original system design parameters, and highlighted design and operating difficulties which must be solved prior to the com-

plete development of the BTS for the military.

D. OBJECTIONS

To the uninitiated the balloon system seems more vulnerable than it really is. The use of nonflammable helium versus the hydrogen which accounted for the fire and explosion hazards of the older balloons has eliminated these dangers. Bursting or sudden loss of inflation gas is prevented by the low inflation pressures used. These balloons have an internal pressure very near that of the surrounding atmosphere, and a puncture results in a loss of gas at a steady slow rate rather than the crippling sudden rush imagined.

The real dangers to the balloon come from the natural elements -- wind, snow, ice, and lightning. Wind causes a dimpeling effect which increases the coefficient of drag in the balloon to the point where normal operations are impossible at wind velocities above 35 knots. Snow and ice are less prevalent but can prevent normal operations or cause damage due to increased weight. Lightning is a very real danger, but with proper shielding gear and adequate grounding, the balloons have been successfully protected from this threat.

E. DISCUSSION

At the present time several methods involving the use of cranes are being developed to provide a container discharge capability; however, all of them are clearly limited in the vertical and horizontal distances over which they can transport containers. In an unimproved area of discharge, the

crane would only serve to transfer containers from the ship to lighterage, and it would be necessary to further discharge the containers at the beach area by another crane. If the ultimate discharge point were further inland than the beach crane could reach, an additional intermediate means of transport and unloading would need to be provided. This double handling of containers in the amphibious area of operations, with its associated coordination requirements at the interface points, has been identified as contributing to delays that would create problems during the support of a Marine Amphibious Operation. These problems can be avoided in a transport system capable of moving the containers directly from the ship to a beach discharge site. The BTS described here has this feature, and a great deal of flexibility would be introduced into the Navy amphibious support capability if a Naval Balloon Transport Facility (NBTF) were established.

Although commercial BTS operators may consider the single most important factor relating to the improvement of balloon systems to be the practical development of the aerodynamically-shaped balloons similar to the Family II balloon, the NBTF probably will not use them. The ruggedness and simplicity of the natural-shaped balloons make them a better choice for the NBTF.

F. THE NAVY BALLOON TRANSPORT FACILITY (NBTF)

When formed and established, the NBTF should be operated by the Navy Cargo Handling and Port Group (NAVCHAPGRU). The mission of NAVCHAPGRU is "to provide immediate supervisory cargo handling and port control capabilities to fleet and

area commanders for support of Naval operations world-wide". Specific tasking also makes NAVCHAPGRU responsible for loading and offloading Navy and Marine Corps cargo carried in support of amphibious warfare requirements and providing cargo handlers for commitments in support of Naval operating forces. Therefore, locating the NBTF within NAVCHAPGRU has the dual advantage of increasing the capability of the command tasked to discharge commercial ships in support of logistics-over-the-shore operations and making the NBTF available on a contingency basis for a variety of uses.

Equipment and personnel requirements necessary for the establishment of a NBTF have been identified. A one-balloon NBTF could be established within NAVCHAPGRU with an expenditure of $3.5 million (1975 dollars) and the addition of only six billets.

Geographically speaking, locating the NBTF with NAVCHAPGRU at Williamsburg, Virginia also has the advantage of being near the Army Transportation Schools at Ft. Eustis, Virginia so Army personnel could also train with the NBTF with no further expenditure of transportation or TDY funds. This provides maximum training exposure to the Department of Defense.

X. CONCLUSIONS

The concept of the Balloon Transport System (BTS) has been demonstrated to be technologically feasible. All military feasibility studies, experiments, and tests involving the use of a tethered balloon system have, without exception, been concluded on a postive note. Evidence exists that the tethered balloon is comparable in vulnerability to all other alternative container-handling systems now in existence or proposed, and cost analysis comparisons of the BTS against other alternative methods will reveal that the system is extremely cost effective.

It is important that one keep the proper perspective when evaluating the results of military BTS experiments. In all cases these experiments used system components which were designed for very specialized applications in a totally different environment from that for which they were intended. The high degree of success of these components indicates a real potential beyond the mere test figures or observations reported, and it demonstrates the high degree of success that a NBTF would achieve.

The tethered BTS employed for the Joint Army-Navy tests at Ft. Story, Virginia was not a prototype of the system which would be required for a military logistics role. It was instead an assemblage of available existing equipment intended to assess concept feasibility, limitations, and obtain technical data which would be required in further

development. Several factors had major impacts on the wind sensitivity of the balloon system used in the Joint Army-Navy tests.

First, the system originally intended for testing utilized a new, modern, 620,000 cubic-foot balloon which had an installed passive ballonet designed to increase the balloon's ability to retain its shape and prevent dimpeling. This new balloon, however, deflated due to a faulty zipper located on the lower portion of the envelope. On-site repair was not effected due to the warranty conditions associated with the manufacture of the balloon; it could have been repaired on-site but was not due to legal rather than physical restrictions. The 630,000 cubic-foot balloon was replaced with a 530,000 cubic-foot balloon supplied from a different source which was similar to the balloons used a decade ago in the pioneering efforts which first proved that natural-shaped tethered balloons were practicable for use in the logging industry.

Second, throughout the various operations attempted, mooring of the LST/BDL-simulated containership, LCU, and warping tugs in the operations area proved to be difficult and time-consuming. In fact, operating the BTS at sea required positioning and holding of these craft within tolerances less than those possible with their conventional mooring capabilities; i.e., anchors rather than preset mooring points.

Third, since leased equipment was used, balloon operations were approached cautiously. As a result, these operations do

not necessarily represent what might have been attempted if government-owned assets had been used.

The balloon is inflated by introducing helium into the balloon to form a bubble at the top of the envelope causing the balloon to stand straight up in a slack condition. When the balloon is in this slack condition, it is most susceptible to dimpeling and subsequent wind damage. Dimpeling, as previously stated, is a condition which occurs when the windward face of the balloon is flattened by the wind's force. The flattened face then expands and offers more resistance to the wind, and, if the wind is strong enough, the balloon flops around or is beaten about and can be damaged. Dimpeling is reduced by either an increase in internal pressure or a decrease in the wind. The aforementioned inflation technique was used in the Joint Army-Navy Test, and it was correctly labelled wind-sensitive. With slight alteration of existing technology, however, there are several alternative methods of inflation that could prove to be less wind-sensitive. For example, launching in higher winds can be accomplished with a technique which exposes as little of the balloon envelope as possible to surface winds during the inflation process. This is accomplished by feeding the balloon through a roller assembly, keeping the uninflated portion of the envelope parallel to the ground. Another possibility is to use a huge net to hold the inflating balloon on the ground and under control during the inflation process. Finally, it has been suggested that a balloon launch could be accomplished from the deck of a ship, which would be free to steam on var-

ious courses or headings enabling it to create a relative wind of zero on the ship's deck.

It is important to understand that alternative launch techniques do exist and that their use would greatly extend the identified limits of the BTS. The establishment of a NBTF, as previously described, is technically possible and, in fact, represents a sound approach to the many problems and costs involved in discharging containerships across unimproved beaches.

XI. RECOMMENDATIONS

The following recommendations are made concerning the development of a Navy Balloon Transport System (NBTS):

1. Conduct a study to refine existing data in the areas of containership and balloon mooring and angles and clearances for working containerships and to establish factual offloading rates for various equipment and environmental conditions.

2. Develop a prototype full-scale system taking advantage of the present advances possible with existing technology. Test the prototype in actual operations with the discharge of containers from a containership across an unimproved beach. Develop standard operating procedures for the operation of the BTS.

3. Provide the U.S. Navy Cargo Handling and Port Group (NAVCHAPGRU) with the six additional personnel and the equipment necessary to establish a Naval Balloon Transport Facility (NBTF).

4. Operate the NBTF as a routine procedure in connection with major amphibious exercises to allow personnel to gain confidence and expertise in handling the system.

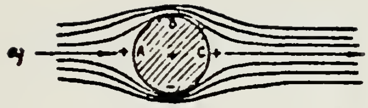
APPENDIX I

One of the critical technical points to be decided in establishing the Balloon Transport System (BTS) is the selection of the balloon design. Because the natural-shaped balloon is simple and rugged and can be maintained and operated in remote areas, it lends itself to the logistic support role in question (28). As this balloon system is presently designed, however, it is limited to operations in winds of less than 25 miles per hour (53). This wind sensitivity is in part due to the relatively high coefficient of drag (C_D), a factor which is inherent in the design shape of the natural-shaped balloon. Coefficient of drag is also of critical importance in determining the system's winch horsepower requirements and potential cycle speed.

The aerodynamically-shaped balloon is a more complex system requiring a relatively sophisticated mooring system and on-board equipment. In addition, the time required for inflation and preparation for operations is more than would be required for a natural-shaped balloon, and the factors relating to large increases in scaling of size are uncertain (28). There are, however, dramatic positive considerations attendent to the aerodynamic balloon. For example, the Family II aerodynamically-shaped balloon can sustain winds of greater than 65 knots, and it has a C_D of 0.15 which would impose a substantially lower horsepower requirement on a winch system than a natural-shaped balloon.

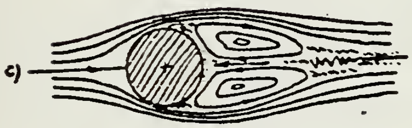
Coefficient of drag can be described as pressure drag caused by friction. Within the considered range of extremely low Reynolds numbers, RN, (to be defined later) the flow pattern around a sphere does not show any separation. In order to understand high C_D's, it is helpful to think of heavy oil as a flowing meduim. The oil particles closest to the body cling to its surface. Because of the viscous friction within the oil, the outer sheets are dragged by the inner ones in the direction of the moving body (72). In order to maintain the movement of the particles against the sphere in relation to each other, a positive pressure originates in front of the body and a negative one behind it (72). This pressure drag is directly caused by viscous friction. The pressure differential in the viscous flow is equivalent to the skin friction; it is the result of the tangential shear forces along the front and rear surfaces of the body. Theoretical and actual flow patterns around two-dimensional bodies are shown in Figure A-1. Note the relatively smooth flows of the very slow speed sphere (Figure A-1a) and the high speed aerodynamic body (Figure A-1f).

Theoretically, if several bodies of different size but identical geometry were immersed in our fluid flow so that their RN's were held constant, their C_D's would be the same (53). This accounts for the constant low C_D of 0.15 calculated for aerodynamically-shaped Family II balloons of various volumes (Figure A-2). Furthermore, when comparing the drag of bodies measured in a wind tunnel with the drag of geometrically similar bodies in unrestricted flow, the RN's



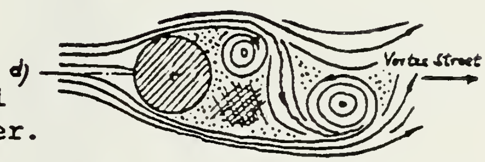
According to non-viscous theory.

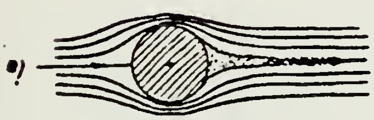
Dynamic analogy.



Cylinder at $R = 10^2$ or 10^3.

Vortex street at higher but still subcritical Reynolds number.





Above the critical Reynolds number (4×10^5).

Around an aerodynamic at higher numbers.

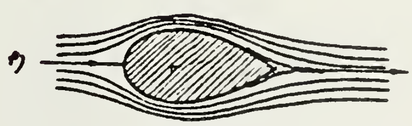


Figure A-1. Theoretical and Actual Flow Patterns around Spheres and Aerodynamically-Shaped Bodies.
Source: Horner, S.F., Aerodynamic Drag.

BALLOON VOLUME (CUBIC FEET)	700,000		1,250,000		1,500,000		2,000,000	
VELOCITY (MPH)	30	60	30	60	30	60	30	60
C_D 0.15	2,666	10,667	3,925	15,701	4,432	17,731	5,370	21,481

Figure A-2. Aerodynamically-Shaped Balloon Coefficient of Drag Values.
Source: Air Force Range Measurements Laboratory, Balloon Feasibility Study.

must be adjusted in order to obtain equivalent drag values (53).

The C_D associated with the natural-shaped balloon is not constant for all volumes and is much more complex than that calculated for aerodynamically-shaped balloons of equal volume. The natural-shaped balloon is acted upon by three environmental forces: gravity, aerodynamic buoyancy, and wind (53). These forces combine to create lifting capacity, and they determine the resulting mooring and winch horsepower requirements. Figure A-3 is a sketch of a natural-shaped balloon moored in a wind with the various forces indicated and identified as follows (53):

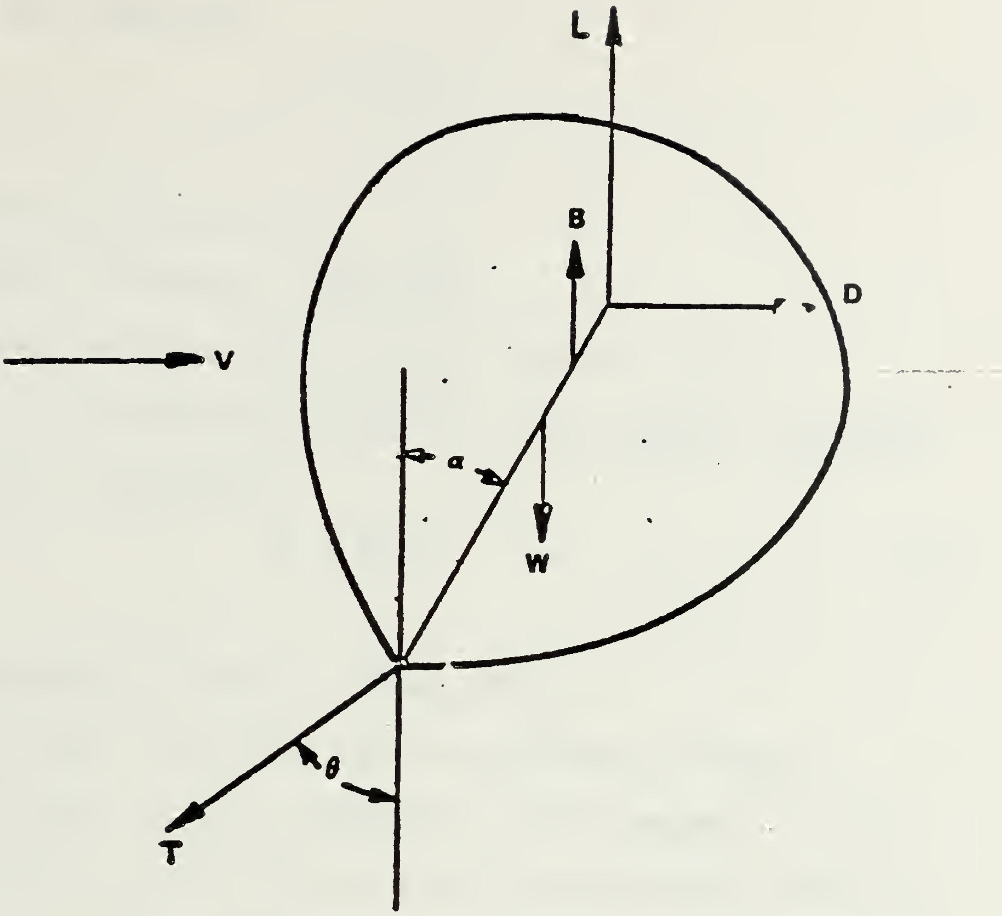
W = the weight of balloon, acting at its center of gravity

B = the buoyancy of the balloon, acting at its center of buoyancy

L = the lift of the balloon, also acting at the center of pressure

T = the mooring tension, acting at the tether attachment. In addition, the figure shows the tilt of the balloon from the vertical as angle α, and the tilt of the mooring tether from the vertical as angle θ (72). Note that the relative velocity between the balloon and the air, a combination of wind speed and towing speed, lies in the plane of the figure (72).

The aerodynamic drag of the natural-shaped balloon is a significant force on the system and depends on speed, density, and viscosity of the atmosphere, as well as the shape, size, and attitude of the balloon in the wind. This is ex-



L = Aerodynamic Lift
D = Drag
V = Wind Velocity
T = Tether Tension at Balloon Base
θ = Tether Angle with Respect to the Vertical
α = Balloon Axis Angle with Respect to the Vertical
B = Buoyant Lift
W = Weight

Figure A-3. Aerodynamic and Natural Shape Relationships.
Source: Joint Army-Navy Balloon Transport System Test, Final Test.

pressed by the equation:

$$D = C_D g A \tag{1}$$

where

D = balloon drag (lbs)

g = dynamic pressure (lbs/ft^2)

A = characteristic area of the balloon (ft^2).

The area, A, is defined as $(V_B)^{2/3}$. The dynamic pressure is given by the equation:

$$g = \tfrac{1}{2}\rho v^2 \tag{2}$$

where

ρ = atmospheric density (slugs/ft^3)

v = wind speed relative to the balloon (ft/sec).

The C_D is a dimensionless parameter which depends on the shape and tilt of the balloon as well as another dimensionless parameter, the Reynolds number, defined as:

$$RN = \rho/\mu \, V \tag{3}$$

or

$$RN = V l/\nu \tag{4}$$

where

V = velocity of the fluid (ft/sec)

l = characteristic linear dimension of the body (ft)

ρ = density of the fluid (slugs/ft^3)

μ = viscosity of the fluid (lbs sec/ft^2)

ν = kinematic viscosity of the fluid = ρ/μ (ft^2/sec).

After observing the forces acting on the balloon (Figure A-3), clearly

$$D = T \sin \theta \tag{5}$$

and, therefore, equation (1) can be written as

$$C_D = \frac{T \sin \theta}{gA} . \qquad (6)$$

If "standard atmosphere" is assumed, "standard sea level conditions" are:

$\rho = 2.378 \times 10^{-3}$ slugs/ft^2

$\mu = 3.74 \times 10^{-7}$ lbs sec/ft^2

$\nu = 1.56 \times 10^{-4}$ ft^2/sec.

Using the above equations, C_D and RN may be calculated for data sets. Figure A-4 shows C_D as a function of RN for data sets obtained during the Joint Army-Navy Balloon Transport System test. The characteristic area, A, for the balloon in equation (6) was defined as $(V_B)^{2/3}$, and the characteristic length, l, in equations (3) and (4) was defined as $(V_B)^{1/3}$ (53). The volume corresponded to the balloon in use at the time of the test -- 620,000 ft^3 and 530,000 ft^3, as appropriate.

The effect of balloon tilt on C_D is ignored in Figure A-4 (53). Balloon tilt values can be correlated to C_D and RN using the equation:

$$C_D = A(1 + B/RN)(1 + C\alpha) \qquad (7)$$

where B = buoyant lift and C = a constant. The balloon tilt is caused by the force of the wind; therefore, α is dependent on the wind speed. Mathematical correlation of α to wind speed has been unsuccessful in tests conducted to date (53), indicating a need for further understanding in this area.

One difficulty in obtaining C_D information for natural-shaped-balloons is the fact that real, natural-shaped balloons

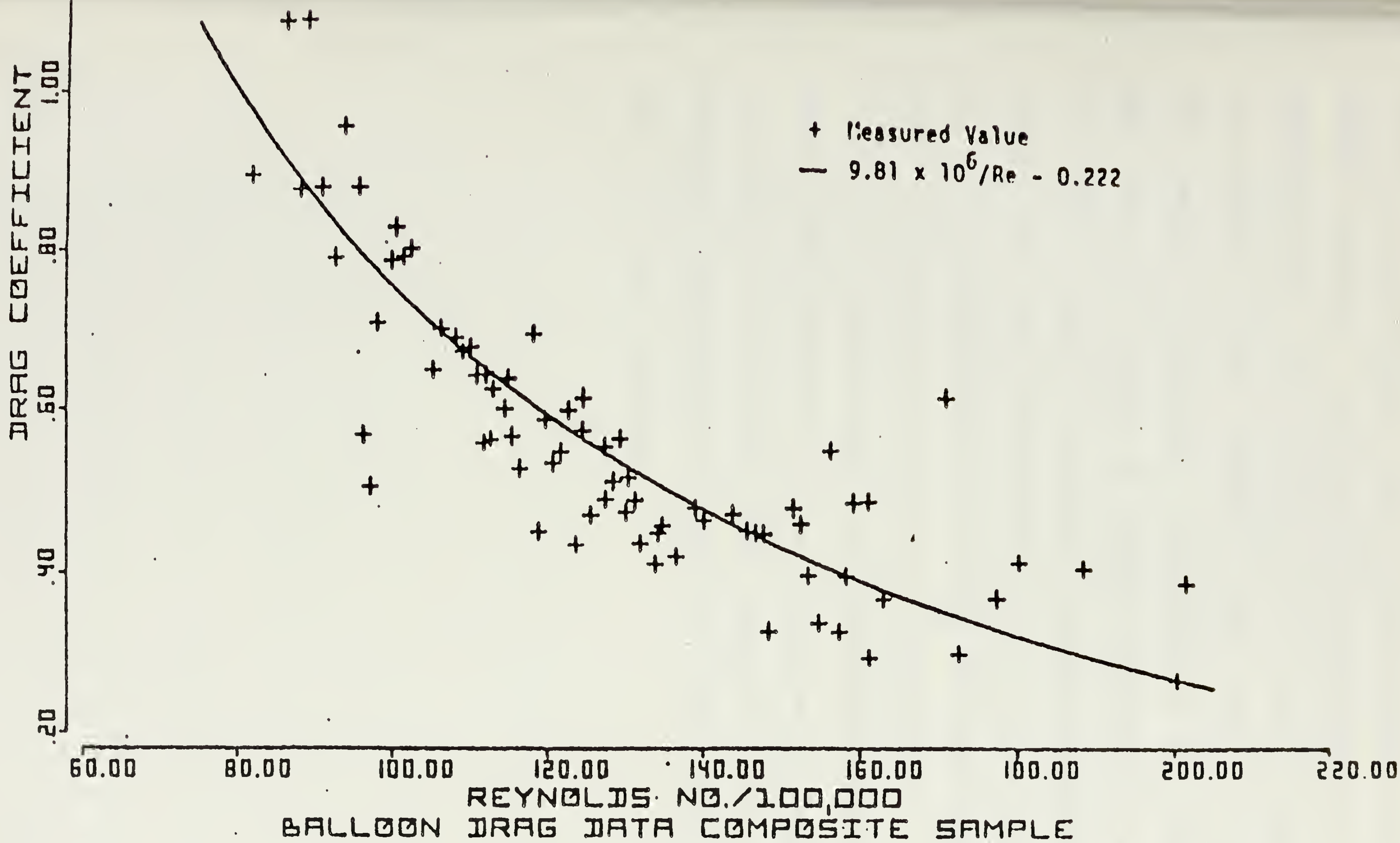


Figure A-4. C_D as A Function of Reynolds Number for Data Derived in the Joint Army-Navy Balloon Transport System Test.

Source: Joint Army-Navy Balloon Transport System Test, Final Report.

diffier significantly from the hard models used in wind tunnel testing. The real balloon differs in at least two respects (53). The pressure of the relative wind deforms the balloon and may create a large wrinkle ("dimple") in the leading surface (53). In addition, the stresses in the skin cause the fabric to "belly" between the seams so that the balloon surface resembles a peeled orange (53). It is thought that these deformations are the primary reason why full-scale measurements of the C_D have exceeded measurements derived from wind tunnel testing by 50 - 100% (53). It is quite possible that the introduction of an on-board, actively-pressurized ballonet system would have the dramatic effect of decreasing wind sensitivity and high C_D's by partially eliminating the dimpeling and bellying which occurs in present designs.

LIST OF REFERENCES

1. U.S. Army Command and General Staff College, Throughput Capacity Estimation, by V.J. Battaglioli, p. 4 - 9, 6 June 1975.
2. U.S. Maritime Administration, U.S. Department of Commerce, Maritime Subsidies, p. 7, 154, May 1974.
3. Department of Defense, Federal Maritime Commision, Department of Commerce, Sealift Procurement and National Security (SPANS), Part 1, p. 24, 2 August 1972.
4. National Research Council, Maritime Transportation, Research Board, Panel on Sealift Readiness, The Commercial Implications of a Military Contingency Call-up of U.S. Flag Merchant Ships, by J.S. Hazard and others, p. 4, 5, June 1975.
5. Department of Defense, Report of Secretary of Defense to Congress on FY 1975 Defense Budget and FY 1975-79 Defense Program, by J.R. Schlesinger, p. 165, 4 March 1974.
6. Military Sealift Command, Sealift Appraisal and Program Considerations, Serial 75M6, p. 21, i, 7 November 1977.
7. Fabry, S.E., Dashiell, R.G., Military Sealift Augmentation Capabilities through 1980, M.S. thesis, Michigan State University, 31 May 1974.
8. Commission on American Shipbuilding, Summary Report, p. 7, v. 1, October 1973.
9. Walker, J.S., Application of Container Technology to United States Marine Corps Tactical Electric Generator Systems, M.S. thesis, Naval Postgraduate School, June 1976.
10. Tabak, H.D., Cargo Containers, p. 5, Cornell Maritime Press, 1970.
11. U.S. Department of Commerce, Annual Report of the Maritime Administration for FY 1975, p. 62 - 72, 1976.
12. Naval Facilities Engineering Command Technical Note N-1386, Naval Beach Group Capabilities in Support of SMLS or Barge/Container Missions, by R.C. Towne and J.A. Drelicharz, p. 7, 28, April 1975.
13. Department of Defense, Joint Logistics Review Board, Logistics Support in the Vietnam Era, Monograph 18, p. 63, 1970.
14. Department of Defense, Joint Logistics Review Board, Logistics Support in the Vietnam Era, Monograph 7, p. 2-9, 2-24, 2-25, 4-15, 4-34, 7-2, 7-10, 1970.
15. "The Joint Logistics Review Board Findings", Army Logistician, p. 10 - 13, v. 2, November-December 1970.

16. David W. Taylor Naval Research and Development Center Report #76-0081, Follow-on and Resupply Shipping Assets for a Representative Marine Corps Situation, by P.E. Friedenburg, p. 15 - 20, January, 1976.

17. Naval Facilities Engineering Command, Container Off-Loading and Transfer System (COTS), p. 1 - 37, March 1977.

18. Naval Civil Engineering Laboratory Technical Note N-1258, Offshore Discharge of Container II Engineering Tests, by R.C. Towne and others, p. 1, 1972.

19. Naval Research and Development Center, Annapolis Laboratory, Task #FD72, Analysis of Container Ship Offloading at Advanced Areas, p. 1 - 14, 15 August 1975.

20. Marine Corps Development and Education Cammand, Final Report on Containerization Requirements for the Fleet Marine Force, 1973 - 1983, p. 1 - 3, 1974.

21. Massachusetts Institute of Technology Inter-Agency Workshop on Lighter-than-Air Vehicles, "Lots" of LTA Applications, by J.S. Brown, p. 668 - 670, June 1976.

22. Massachusetts Institute of Technology Workshop on Lighter-than-Air Vehicles, Ultra-Heavy Vertical Lift System "The Helistat", by F.N. Piasecki, P. 465 - 477, June 1976.

23. Army Command and General Staff College, The Aerocrane in LOTS Operations, by J.R. Hauser, p. 1 - 64, 11 June 1976.

24. Piasecki Aircraft Corporation, Report 97-X-33B, by D.N. Meyers, npn, 10 June 1975.

25. Commander Naval Air Systems Command, Ltr 03p32 dated 6 October 1975, Subj: Aerocrane.

26. Goodyear Aerospace Corporation, Feasibility Study of Modern Airships, p. 104, September 1976.

27. Piasecki Aircraft Corporation, Helistat Ultra-Heavy Vertical Air Lift System Model 97-1C, p. 1 - 12, nd.

28. Range Measurements Laboratory, Balloon Feasibility Study: Balloon Transport Facility for Offloading Container Ships, by J.A. Sechrist and H.E. Reed, p. 2 - 26, 3 - 15 May 1975.

29. Graeter, W.F., "NAVCHAPGRU Tests Sky Hooks", Naval Supply Corps Newsletter, p. 25, March 1977.

30. Flight Transportation Laboratory, Massachusetts Institute of Technology, Assessment of Lighter-than-Air Technology, by J.F. Vittek, Jr., p. 21 - 31, 1976.

31. Massachusetts Institute of Technology Interagency Workshop on Lighter-than-Air Vehicles, Where Do We Go from Here?, by VADM C.E. Rosendahl, USN (ret.), p. XIII - XVII, 1976.

32. Rolt, L.T.C., The Aeronauts, A History of Ballooning, p. 45, 162, 163, 166, 213, Longmans, Green and Co., Ltd., 1966.

33. Massachusetts Institute of Technology Interagency Workshop on Lighter-than-Air Vehicles, Lighter-than-Air, A Look at the Possibilities, by W.F. Shea, p. 285, 287, 1975.

34. Clarke, B., The History of Airships, p. 99, St. Martin's Press, 1961.

35. Massachusetts Institute of Technology Interagency Workshop on Lighter-than-Air Vehicles, Design Aspects of Zeppelin Operations from Case Histories, by W.P. Maiersperger, p. 267, 281, 1975.

36. AIAA Lighter-than-Air Technology Conference, LTA Vehicles Historical Operations, Civil and Military, R.R. Huston and G.L. Fourote, p. 2, July 1975.

37. Massachusetts Institute of Technology Interagency Workshop on Lighter-than-Air Vehicles, Basic Relationships for LTA Economic Analysis, by R.A. Ausrotas, p. 1 - 6, July 1975.

38. Massachusetts Institute of Technology Interagency Workshop on Lighter-than-Air Vehicles, Preliminary Estimates of Operating Costs for Lighter-than-Air Transports, by C.L. Smith and M.D. Andema, p. 7 - 20, July 1975.

39. Massachusetts Institute of Technology Interagency Workshop on Lighter-than-Air Vehicles, Comparative Air Ship Economics, by R. Harthoon, p. 21 - 30, July 1975.

40. Massachusetts Institute of Technology Interagency Workshop on Lighter-than-Air Vehicles, Effect of Present Technology on Airship Capabilities, by R.T. Madden and F. Bloetscher, p. 31 - 40, July 1975.

41. Massachusetts Institute of Technology Interagency Workshop on Lighter-than-Air Vehicles, Air Economics, by R.D. Neumann and M. Hackney, p. 41 - 52, July 1975.

42. Massachusetts Institute of Technology Interagency Workshop on Lighter-than-Air Vehicles, Some Economic Tables for Airships, by R.D. Neumann, p. 53 - 62, July 1975.

43. Massachusetts Institute of Technology Interagency Workshop on Lighter-than-Air Vehicles, A Study of Design Tradeoffs Using a Computer Model, by. S. Coughlin, p. 63 - 74, July 1975.

44. Massachusetts Institute of Technology Interagency Workshop on Lighter-than-Air Vehicles, An Economic Comparison of Three Heavy Lift Airborne Systems, by B. H. Carson, p. 75 - 86, July 1975.

45. Massachusetts Institute of Technology Interagency Workshop on Lighter-than-Air Vehicles, An Approach to Market Analysis for Lighter-than-Air Transportation of Freight, by P.O. Roberts, H.S. Marcus, and J.H. Pollock, p. 76 - 87, July 1975.

46. Massachusetts Institute of Technology Interagency Workshop on Lighter-than-Air Vehicles, Market Assessment in Connection with Lighter-than-Air, by J.E.R. Wood, p. 89 - 111, July 1975.

47. Seibel, C.W., Helium: Child of the Sun, p. 133 - 177, The University of Kansas Press, 1968.

48. The United States Department of Interior Bureau of Mines Bulletin 617, Helium Bearing Natural Gases of the United States, by R.D. Munnerlyn and R.D. Miller, 1963.

49. U.S. Air Force War College Report 5848, Lighter-than-Air Platforms: Helping to Do More with Less, by R.M. Blanchard, p. 6, 40, 169, 1976.

50. Chesapeake Division Naval Facilities Engineering Command, Vulnerability of Tethered Balloon Systems, by C.D. Fitz, p. 4 - 26, 30, 31, 34, 21 September 1973.

51. AFCRL Tethered Balloon Workshop, The Use of a Tethered 15,000 Pound Gross Lift Natural-Shaped Balloon for Remote Logging Operations, by R.A. Pohl, p. 71, 1967.

52. Massachusetts Institute of Technology Interagency Workshop on Lighter-than-Air Vehicles, Two Lighter-than-Air Systems in Opposing Flight Regimes -- An Unmanned Short Haul, Heavy Load Transport Balloon and a Manned Light Payload Airship, by J.F. Vittek, Jr., p. 639 - 671, June 1975.

53. Headquarters Air Force Eastern Test Range, Joint Army-Navy Balloon Transport System Test, Final Report, by H.E. Reed and G.T. Dyer, p. 10, August 1976.

54. The Advanced Research Projects Agency, An Evaluation of the Feasibility of Utilizing Balloon Systems for the Ship-to-Shore Transport of Military Cargo, by C.D. Frite, R.A. Egen, J.O. Frankosky, and D.K. Blue, p. 5, June 1973.

55. "Yemen Primed for Rapid Development", Arab Economic Review, U.S. Arab Chamber of Commerce, Inc., December 1977.

56. Air Force Eastern Test Range, Patrick Air Force Base Report TR-74-042, A Proposal for Providing Logistic Support, by H.E. Reed, 1974.

57. Range Measurements Laboratory, Ship-to-Shore Oregon Demonstration Test, by D.S. Fritz, p. 11 - 12, June 1973.

58. Range Measurements Laboratory, Ship-to-Shore Oregon Test Series II, Final Report, by H.E. Reed, p. 2 - 20, 11 June 1973.

59. Delta Research Corporation, Determination of Coefficient of Drag for a Natural-Shaped Balloon, by D.C. Fritz, p. 5, 28 June 1974.

60. Range Measurements Laboratory, Stapleton Logistics Experiment, by H.E. Reed, p. 1 - 7, 8 July 1974.

61. Range Measurements Laboratory, Ship-to-Shore Oregon Test Series II, Preliminary Report, by H.E. Reed, p. 5 - 9, November, 1973.

62. Naval Facilities Engineering Command, Communication from M.E. Essoglue, Deputy Director Research, To Author, 13 March 1978.

63. Naval Beach Group Two, *Joint Army-Navy Balloon Transport System Test, Preliminary Report*, by G.T. Dyer, p. 1 - 12, 8 March 1976.

64. Stapleton, J.R., "Balloon Transport System", *Army Logistician*, p. 23, July - August, 1975.

65. Flying Scottsman Company, Eugene, Oregon, Communication from H.E. Reed, Research and Development Engineer, To Author, 16 January 1978 and 13 April 1978.

66. DDRE letter to OASD I&L (September - October) 1974.

67. Joint Logistics-over-the-Shore Test Director, Joint Army-Navy Logistics-over-the-Shore Test Series, Letter ATSP-CTD-LOTS, Dated 3 February 1975, Subj: Letter of Instruction, Joint LOTS Test Directorate, for Joint Army-Navy Balloon System Test, Enclosure (1), Test Plan, Joint Army-Navy Balloon Transport System Test.

68. David W. Taylor Naval Research and Development Center, Annapolis, Maryland, Communication from C.C. Stevens, Project Engineer, Mobile Support Systems Group, To Author, 13 April 1978.

69. Acme Joint Service Pay Tables, Effecitve Date 1977.

70. Naval Personnel Programming Support Office, Occupational Standards Department, *Annual Enlisted Manpower Billet Costs for Life Cycle Planning (Rough Draft)*, npn, 12 February 1975.

71. B-K Dynamics, Inc., *Bureau of Naval Personnel Users Manual, Billet Cost Model*, November 1976.

72. Hoerner, S.F., *Aerodynamic Drag*, The Otterbein Press, p. 16, 1951.

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